FINAL REPORT

SEDIMENT TRANSPORT AND CHANNEL SHOALING ANALYSIS FOR THE PROPOSED NORTON BASIN ENTRANCE CHANNEL

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The U.S. Army Corps of Engineers, New York District (USACE-NYD) has initiated Ecosystem Restoration Work for Norton Basin and Little Bay, located within Jamaica Bay, New York. A variety of placement alternatives are to be considered as potential solutions to the increased volume of dredged sediment produced within the Port of New York/New Jersey.

One potential use of the dredge material is for bathymetric re-contouring. A number of historic borrow pits exist within Jamaica Bay, that were created throughout the early 20th century to provide fill material during urban development. These pits, typically 55 to 60 feet deep, are now considered sources of poor water quality (CSA, 2004). It is expected that filling these pits and re-contouring the bathymetry to historic conditions will provide both a placement area for dredged material and, simultaneously, will improve the water quality and ecology of the re-contoured areas.

Six candidate pits exist in Norton Basin and Little Bay. In order to provide access to the borrow pits in these basins, a channel will need to be dredged and maintained. There is currently a narrow channel in the entrance to Norton Basin, hereafter referred to as an inlet, providing limited access. However, this channel was created in 1938 and its current condition, based on recent bathymetric surveys, indicates that it is unsuitable for modern navigation related to dredge material placement. It is proposed that a new channel be created in the Norton Basin inlet to provide access to the existing borrow pits in Norton Basin and Little Bay.

Channel dredging historically enhances sediment transport in the area of the channel and typically will require maintenance dredging after the initial channel is created. The purpose of this analysis is to investigate the potential for channel infilling of the proposed Norton Basin entrance channel.

Norton Basin and Little Bay are two dead-end basins located on the north shore of the eastern Rockaway Peninsula, in the Borough of Queens, New York City (NYC). The basins are drained by a common channel into the southeastern edge of Jamaica Bay. NOAA Navigational Chart #12350 for Jamaica Bay, Norton Basin and Little Bay is shown in Figure 2-1, with a close-up view of Norton Basin and Little Bay shown in Figure 2-2.

Historically, Jamaica Bay, including Norton Basin and Little Bay, was a shallow inter-tidal salt marsh. Development over the last two centuries has drastically altered the configuration and hydrology of the entire Jamaica Bay. It is estimated that Jamaica Bay, including Norton Basin and Little Bay, once encompassed 25,000 acres total, with 16,000 acres of inter-tidal marshes and 9,000 acres of open water with an average depth of 3 feet. Currently, Jamaica Bay has been reduced to 13,000 acres total with 4,000 acres of inter-tidal marsh. The average depth has increased due to channel dredging. These changes, combined with other alterations, like the construction of John F. Kennedy International Airport (JFK) runway extension completed in 1962, have greatly altered the hydrodynamic characteristics of the bay. The land use of the surrounding area is now predominantly dense residential. A more detailed history of the area is available in a report by Rhoads et al. (2001).

The most significant impact to Norton Basin and Little Bay was the excavation of borrow pits, beginning in 1938, to provide fill dirt for the creation of the Edgemere Landfill. At that time a channel was dredged at the entrance to Norton Basin to provide access for the excavation. Portions of the original channel remain today. In its present state, the channel is considered narrow, 30 feet wide in some sections and about 10 feet deep at MLLW. However, portions of the existing channel may be as shallow as 4 feet at MLLW and a sill exists at the intersection of Norton Basin channel and Grassy Hassock Channel (personal communication, HydroQual).

The Edgemere Landfill now forms the northwestern boundary of Little Bay and Norton Basin. In addition to defining the current shoreline of Norton Basin and Little Bay, the landfill may act as a continuous source of sediments. It is estimated that in the 1980's runoff from the landfill yielded about 1,128 cubic yards of sediment per year to the adjacent waters (NYSDEC, 1991). However, since the landfill has been closed and capped, the sediment load has likely been significantly reduced.

In its present state, Norton Basin has three 45 to 50 ft deep (MLW) borrow pits, with a planar surface area of approximately 55.5 acres, a bottom surface area of approximately 56.9 acres, and a total volume of approximately 2.3 million cubic yards (MCY). Little Bay is located southeast of the Edgemere Landfill. It has three 60 to 65 ft deep (MLW) borrow pits, a planar surface of approximately 24.5 acres, a bottom surface area of approximately 25.2 acres, and a total volume of approximately 1.2 MCY (Vittor, 2001).

The proposed channel is 50 feet wide at the bottom, 100 feet wide at the top and 12 feet deep at MLLW. It will be aligned with the existing channel, with its centerline shifted slightly to the east, and it will extend from the Grassy Hassock Channel to the first borrow pit in Norton Basin. The new dimensions of the channel will allow access to the basins for equipment used in the dredging operations throughout the Port of New York/New Jersey.

3.1 BATHYMETRY

The bathymetry for Jamaica Bay, Norton Basin and Little Bay is available in NOAA chart #12350, shown in Figures 2-1 and 2-2. The deep pits in Norton Basin and Little Bay are evident, as is the deep portion of Grassy Hassock Channel which runs east-west across the entrance to Norton Basin. The narrow channel remaining in the entrance to Norton Bay is about 10 feet deep at MLLW, according to the chart, but the reported sill between the entrance channel and the Grassy Hassock channel is not evident. Shoals exist just outside and along the entrance to Norton Basin, which are classified as 'foreshore' areas by NOAA, indicating that they may be periodically submerged and subsequently exposed during the tidal cycles.

Digital bathymetric data was available from three sources. The first was obtained from the GEOphysical DAta System (GEODAS), a division of NOAA's National Geophysical Data Center's (NGDC). The GeoDAS database was accessed via an on-line search and data was retrieved from NGDC's NOS Hydrographic Surveys database. The digital download of hydrographic sounding data was a compilation of all depth soundings collected in Jamaica Bay from 1927 to 1996. Hydrographic survey bathymetric data was referenced to a horizontal datum of NAD83 and a vertical datum of Mean Low Water (MLW).

A second set of bathymetric data, provided to URS by HydroQual, was collected in 1995 and is not included in the GEODAS database. This dataset overlapped portions of the GEODAS data, often appearing to include more recent bathymetric information in some portions. This dataset was reported in latitude/longitude coordinates. The vertical datum was not actually reported but deduced by comparing the 1995 data set with similar areas in the GEODAS dataset.

A third set of data was available from a high-resolution survey of Norton Basin and Little Bay, covering the borrow pits in each basin and the deeper portions of the entrance channel. The Norton Basin bathymetric data was supplied via a bathymetric map, which was converted into a GIS shapefile. The horizontal data was reported in NAD83 meters and the depth data was reported in feet with an unknown vertical datum. Although the vertical datum was not actually reported, it was deduced by comparing the 1995 data set with similar areas in the GEODAS dataset.

The 1995 dataset did not appear to be very consistent with the GEODAS data, and often the GEODAS data indicated deeper water depths, ranging up to a two meter variance. These findings are counter-intuitive, as it would be expected that the more recent 1995 data should include all of the current channels which may not have existed during earlier surveys offered in the GEODAS database. However, the 1995 data did include a survey of the Grassy Hassock Channel, not available in the GEODAS data.

While constructing the digital bathymetry, an order of preference was established as (1) the Norton Basin/Little Bay high-resolution bathymetry, (2) the GEODAS data and (3) the 1995 survey data. The only exception was the use of 1995 dataset in the Grassy Hassock area. The primary issue with using the 1995 data to replace the GEODAS database in the Grassy Hassock Channel area occurred at the western end of the channel, where the 1995 dataset did not provide complete coverage of the channel. Therefore, the bathymetry at the western end of the 1995 dataset was extended westward and blended with the GEODAS dataset.

The three bathymetric survey datasets were combined with coastline data from NOAA's ENC database, which supplies data as ArcView shapefiles. The land area polygon shapefile for region US4NY1AM was used to outline the model domain. The use of this coastline dataset was necessary, as the bathymetric data often do not include an accurate representation of the shallow areas near islands and shorelines. Navigational limitations of the survey vessels traditionally account for the missing data. When data gaps still existed after merging all three bathymetric datasets, the final merged dataset was manually augmented with estimates of shallow water depths, using the NOAA navigational chart #12350 for guidance.

Figure 3-1 shows the composite bathymetry of Jamaica Bay and the Norton Bay and Little Bay system based on the digital datasets.

The entrance to Norton Basin is not well represented in the NOAA chart or any of the digital datasets, except for a small section extending from the Norton Basin borrow pit outward towards Jamaica Bay. Missing data include the elevation of the inter-tidal shoal, the sill at Norton Basin entrance and critical channel geometry extending outward of the small section in Norton Basin. This is problematic from the standpoint of assessing sediment transport in the proposed channel, as information on the existing channel is critical to an understanding of transport conditions in the area.

The steeper side walls of the Norton Basin and Little Bay pits have slopes in the range of 20 degrees. As non-cohesive sands typically can sustain side slopes of 30 degrees when not forced by waves or currents, the slopes found in the pits do not necessarily require cohesive bonding to remain stabile. These steeper slopes occur in water depths below 7 meters (21 feet) and are not likely to be subjected to significant hydrodynamic forcing.

3.2 AERIAL PHOTOGRAPHY

Aerial images of Jamaica Bay, Norton Basin and Little Bay are available from the 1950's to present from a variety of sources. Of the images available from the USGS archives acquired from the EarthExplorer, four images were found to be of sufficient quality and resolution. These images are assembled in chronological order in Figures 3-2 and 3-3. It is clear in the 1954 images, that the construction of the Edgemere landfill was still ongoing; construction was completed sometime before 1966. At that time, the major features of the Norton Basin and Little Bay shoreline were established. Changes since 1966 have been relatively minor and predominantly related to the shoals and evolution of the Norton Basin Entrance Channel.

Since 1996, the images indicate that the shoals adjacent to the Norton Basin Entrance Channel have changed little, if any at all. It is important to note the tide range in the area is on the order of 6 feet, and therefore, the visibility and discernable shape of the channel and shoals in these images is likely affected by the current tide level at the time the photographs were taken. Also, the images differ in their reflectance and granularity. Thus, it is not possible to accurately interpret the shoal geometry, or changes in geometry, from the photos. The 1955 aerial image does not clearly illustrate whether the shoals yet existed in a geometry similar to their present state. However, it is likely, that the shoal pattern evolved to near equilibrium in the late 1960's.

The shoals may be exposed in the 1974 image, consistent with their designation as inter-tidal regions on the NOAA nautical chart. Note that there are no ebb or flood tide shoals evident in the aerials or the bathymetric data. There is a crescent shaped raised portion on the eastern shoal that may be submerged at high tides. Evidence of the sill or shallow depths in the channel are not discernable in the images.

3.3 SEDIMENTS

Grain-size data in Norton Basin and Little Bay are available form two recent studies. In the first study (Barry A. Vittor and Associates, Inc., 2001), four surface grab samples were collected in Norton Basin and one in Little Bay. The Norton Basin sample stations were located (1) at the mouth of the entrance channel, (2) in shallow water in basin interior and (3&4) in two deep water samples in the borrow pits. However, the water depths for these stations were not reported. The Little Bay station was located in deep water in one of the borrow pits. Sediment descriptions of the surface samples indicate that the deeper sediments are mostly fine-grained clay and silty clay. The shallow water samples consisted of coarser-grained, clayey sands. The report states that the borrow pits tend to have soft, muddy substrates, while the shallower areas of the basin include sandy substrates.

A second set of sediment samples were collected in a subsequent study (Barry A. Vittor and Associates, Inc., 2002). Surface grab samples were collected at a total of 10 stations in Jamaica Bay, Norton Basin and Little Bay, primarily to characterize sediment chemistry in the area. (Figure 3.4) Three replicate samples were collected at each station. In addition to sediment chemistry analysis, sieve and hydrometer tests were completed on a subset of the samples to characterize the sediment grain-size distribution. The results of the analysis are consistent with the earlier descriptive analysis, although the sieve and hydrometer results indicate that the sediments are predominantly soft, cohesive silt with varying amounts of sand and clay. The sands, when present, are in the fine sand range (0.06 to 0.32 mm range).

As part of a water quality sampling program conducted from 2000 through 2002 (NYSDEC, 2003), water quality sampling was conducted at 10 ft intervals throughout the water column. Anecdotal evidence suggests the existence of a persistent nephloid layer of very turbid water at the base of the pits in Norton Basin and Little Bay. During the August 4th and 31st, 2000 sampling events, Niskin bottle samplers were used to collect samples at depth. The results showed a change from clear to turbid consistency in the 35 to 39 ft depth range in Norton Basin and in the 55 to 60 feet depth range in Little Bay.

These data suggest that the pits are acting as sediment traps. Fine-grained sediments are advected and/or diffused in the pit areas. Once they settle to the deeper and less energetic depths of the pits, they slowly consolidate or flocculate and deposit on the bottom. Sedimentation rates of fine-grained material in a borrow pit in Grassy Bay have been estimated to average about 1.5 cm/yr., as suggested during the Scientific Symposium and Public Forum on Jamaica Bay's Disappearing Marshes, held on March 3rd, 2004 at the New York Aquarium.

3.4 TIDES

There are no long term tide datasets available within Jamaica Bay. However, short-term local tide data was recorded within Jamaica Bay during July and August of 1988 at the Rockaway Inlet, the entrance to Jamaica Bay, and also at the Norton Basin inlet. Data are reported on fifteen minute intervals in Julian Days (EST) and is reported in MLLW (ft).The nearest long term tide data are available at NOAA's Sandy Hook, NJ monitoring station. The time series data were downloaded from the NOAA's Tides Online web page and a representative time series plot of the data is presented in Figure 3-5. There is a spring-neap cycle evident in the data, and the spring tide range is approximately 2 meters.

The local tide data are shown with the Sandy Hook time series in Figure 3-6. The vertical datum for this data was not reported, but appears to be consistent with the MLLW, based on the plots of the local tide datasets. There is little difference in the tide amplitudes at Sandy Hook versus Jamaica Bay. The small differences could easily be attributed to accuracy limitations of the recorders, and are insignificant from the stand point of accessing sediment transport. The data do indicate that the Sandy Hook tide lags those in Jamaica Bay by about one hour, which is counter-intuitive and likely due to errors in designating the time reference. Again, these differences do not have any affect on the sediment transport analysis.

3.5 CURRENTS

Current measurements were collected as part of the 2002 study (Barry A. Vittor and Associates, Inc., 2002). S4 current meters were deployed on moorings at various stations for 6 to 24 hour periods intermittently throughout June, July and September of 2002. The stations were located in the borrow pits or inside the Norton Basin and Little Bay inlet channels. In all cases the moorings were in water depths greater than 45 feet. The S4 current meters were arranged to collect near surface, mid-depth and near bottom current speeds and directions.

The measured currents in the borrow pits tended to be very low, typically less than 5 cm/s and seldom more than 10 cm/s. Current patterns in the surface and mid-depth levels were consistent with tidal flows in Norton Basin, but less consistent in Little Bay. Often the currents in the pits were poorly correlated with the mid-depth or surface currents. Overall, the currents showed complex patterns. In most cases, wind forcing may have explained some of these current patterns.

3.6 WINDS

A review of the available wind data from the National Climatic Data Center (NCDC), a division of the National Oceanic and Atmospheric Administration (NOAA), indicated that there was sufficient wind data from John F. Kennedy International Airport (JFK, WBAN # 94789), to characterize long-term meteorological conditions at the Site. A fifteen-year wind dataset was collected from JFK ranging from January 1, 1990 through December 31, 2004.

A wind rose plot of the wind data from JFK is shown in Figure 3- 7. The wind rose diagram indicates the dominant wind directions generate from due south and from the northwest, with the northwest winds producing generally higher wind speeds. Coincidentally, the northwest dominant wind direction loosely correlates with the dominant fetch direction upwind of the Norton Basin entrance.

The wind speed and directional data are shown in tabular form in Table1. The data indicate that the majority of wind speeds are slower than 6 m/s. Less than four percent of wind speeds exceed 10 meter per second, indicating a limited ability for wind-induced wave generation.

TABLE 3-1

WIND SPEED AND DIRECTIONAL DATA
JFK Airport Wind Data

		Wind Speeds (m/s)						
		0-2	2-4	4-6	6-8	8-10	10+	Sum
Wind Directional Bins (deg)	0	0.21	2.00	2.30	1.26	0.42	0.16	6.35
	22.5	0.25	2.19	2.17	0.97	0.34	0.13	6.06
	45	0.31	2.39	1.96	0.90	0.35	0.17	6.09
	67.5	0.44	2.07	1.26	0.54	0.18	0.10	4.61
	90	0.32	1.46	1.04	0.56	0.21	0.10	3.69
	112.5	0.30	1.26	1.13	0.45	0.13	0.06	3.34
	135	0.24	1.33	1.17	0.41	0.09	0.06	3.30
	157.5	0.25	1.55	1.60	0.60	0.21	0.14	4.36
	180	0.30	2.71	3.62	2.13	0.90	0.37	10.03
	202.5	0.23	2.84	3.51	1.44	0.41	0.11	8.54
	225	0.25	3.13	2.70	1.07	0.25	0.05	7.45
	247.5	0.17	2.72	3.02	1.21	0.40	0.21	7.72
	270	0.11	1.46	2.04	1.54	0.75	0.40	6.29
	292.5	0.09	0.97	1.97	1.89	1.17	0.79	6.88
	315	0.09	1.14	2.47	2.29	1.45	0.90	8.34
	337.5	0.13	1.49	2.62	1.77	0.73	0.23	6.96
	Sum	3.68	30.70	34.59	19.04	8.01	3.98	

3.7 WAVES

A search for wave data within Jamaica Bay, Norton Basin or Little Bay produced no data. Therefore, in order to characterize the wave climate in the area, we applied wind transformation methods to the long term wind data. The geometry of Jamaica Bay limits wave propagation to Norton Basin and Little Bay from external sources, and therefore, the waves in the area are likely to be predominately locally wind-generated.

The transformation methods described in the USACE Shore Protection Manual (USACE, 1986) were used to make the transformation. The method accounts for the effects of fetch, water depth, and event duration on wind-generated waves. The method consists of a series of nomographs that relate the wave height, period and duration for saturation to the fetch, depth and wind speed.

Two fetch directions were identified on the NOAA charts that would potentially produce waves in the vicinity of the Norton Basin entrance. One is centered about due north, extended approximately 15 degrees east and west, covering the region adjacent to the JFK runway extension. The second is from the west-southwest direction, and is aligned along the Grassy Hassock Channel. For the northern fetch, the length is approximately 5000 meters, and for the WSW fetch the length is approximately 3000 meters. The representative water depth for both fetches is 6 meters.

The transformation was applied for wind directions aligned with the two selected fetch directions and the results are shown in Tables 2. The estimated wave heights are relatively small, on the order of 10 cm, with short periods, on the order of 2 to 3 seconds. The duration for the waves to reach these heights is typically less than an hour, often on the order of 15 minutes. The largest wave estimated is 0.88 meters, for a 22 m/s (~50 mph) wind blowing from the west.

TABLE 3-2

WAVE HEIGHT, WAVE PERIOD, AND WIND DURATION SATURATION TIMES
JFK Airport Wind Data

	Wind Speed (m/s)	Wave Height (m)	Wave Period (s)	Saturation Time (min)		Wind Speed (m/s)	Wave Height (m)	Wave Period (s)	Saturation Time (min)
337.5, 0, 22.5 Degree Wind Bins 5000 m Fetch	0-2	0	0	0	247.5 and 270 Degree Wind Bins 3000 m Fetch	0-2	0	0	0
	2-4	0	0	0		2-4	0	0	0
	4-6	0.23	1.8	45		4-6	0.22	1.55	58
	6-8	0.30	2	35		6-8	0.25	1.8	48
	8-10	0.40	2.2	30		8-10	0.30	1.9	42
	10-12	0.46	2.4	27		10-12	0.40	2.1	38
	12-14	0.55	2.5	24		12-14	0.46	2.2	35
	14-16	0.65	2.65	22		14-16	0.55	2.3	30
	16-18	0.54	2.75	20		16-18	0.62	2.4	28
	18-20	0.78	2.9	19		18-20	0.70	2.5	26
	20-22	0.88	3	18		20-22	0.74	2.65	25

Wave generation in the vicinity of Norton Basin entrance channel is fetch-limited and yields short period, small waves. Waves within Norton Basin and Little Bay will also be small, due to limited fetch lengths within the confines of each basin.

3.8 SITE SPECIFIC EMPERICAL DATA

There is a channel shown on the NOAA Chart (Figure 2-2) the leads to Motts Basin just north of Norton Basin. The channel is maintained to 15ft MLLW depth. The dredging history of this channel would provide site-specific empirical data for accessing future conditions in the proposed channel for Norton Basin. Motts Basin and the sloughs leading into it comprise a smaller surface area than Norton Basin and Little Bay, and the entrance area is slightly more sheltered than the Norton Basin entrance area, but the dredging history would provide some indication of potential shoaling rates in the area and could be used as a reference for constraining potential estimated Norton Basin shoaling rates. Unfortunately, efforts to acquire such data did not yield any useful information at this time. The only information available from the USACE NY District indicated that the channel was initially dredged during March through June of 1961. The dredge volume was 801,389 cubic yards. There are no maintenance dredging records associated with the USACE records, however, the channel is not maintained by the Corps, and there may be other information available via other sources. Efforts are ongoing to determine if there are other sources of useful information.

3.9 SUMMARY

The data available for characterizing Norton Basin and Little Bay provide insight into the historic evolution and current sediment transport processes in the system. The currents are tide-driven and wind-driven and tend to be low within each basin. The geometry of Jamaica Bay limits wave propagation into Norton Basin and Little Bay, and therefore, the waves in the area are likely to be locally wind-generated. The fetches are short and water depths are shallow except for the borrow pits and the deeper, wider Grassy Hassock Channel. Therefore, the waves are expected to be small. However, there is a significant tidal range in Jamaica Bay, on the order of 2 meters during the spring tides, which might produce significant tidal currents through the entrance channel.

The sediment sampling in the area at medium and deep sample depths indicates that the sediments are composed of mostly silt with varying fractions of sand and clay-sized particles. There is a trend from sandy substrates in shallow water to muddier deposits in deeper water. No sediment samples exist for the shallower regions, such as the shoals in the Norton Basin entrance or the sill at the juncture of the Grassy Hassock Channel and the Norton Basin entrance channel. The surface sediments comprising the shoals have been identified as gravelly sand, based on visual observation during filed reconnaissance (personal communication, USACE),

Water quality studies and sediment rate analyses indicate that the deep borrow pits are likely acting as sediment traps for fine-grained sediments transported as suspended load during energetic events. The presence of a nephloid layer in the bottom of the Norton Basin and Little Bay pits is strong evidence of this process. The development of a muddy deposit in a pit in the Grassy Bay, with an estimated accumulation rate of 1.5 cm/yr, is also strong evidence.

The data available for analysis are not sufficient to determine the nature of the inter-tidal shoals adjacent to the Norton Basin Entrance Channel. Historically, inter-tidal areas exist throughout Jamaica Bay, and it is possible that these shoals are remnants of previously existing inter-tidal areas. It is also possible that the dredging of the entrance channel into Norton Basin altered the hydrodynamic regime, promoting sediment transport in the area and the built-up of the shoals.

The aerial photographs indicate that during the 1954 – 1966 periods, the Edgemere Landfill was still under construction. While the Edgemere Landfill was being completed prior to 1966 and for some time afterwards, its construction may have accounted for a larger sediment supply to the Norton Basin entrance area. Thus, it provided a large volume of available sediment for re-distribution by the prevailing currents and waves. Once this supply was reduced (soon after 1966), the system approached a new equilibrium state that is seen to be fairly persistent in the aerial images.

The sill reported at the juncture of the Norton Basin Entrance Channel and Grassy Hassock Channel is not discernable in the NOAA chart, the digital bathymetric datasets or the aerial images. However, it is assumed that the sill is a historic feature, and not a recent development. This sill could have been created by ongoing local sediment transport and could potentially be an part of an ebb tide shoal system, or formed by channel infilling. Tidal flows in the channel may have been overwhelmed by large sediment supplies during the construction of the Edgemere Landfill, causing deposits in the entrance channel that eventually lead to the sill. However, it could also have been formed by dredging process. Since the Norton Basin entrance channel was first dredged in 1938, it probably extended into what was historically a shallower Grassy Hassock bathymetry. Once dredging was started to create the Grassy Hassock channel, the dredging process may have been excavated deeper, and sediment released during the dredging might have supplied the material that eventually comprised the sill.

The lack of detailed bathymetric and sediment grain-size data in the shallow portions of the area limit the interpretation of the data in terms of possible sediment transport mechanisms and rates associated with the channel, sill and shoals.

However, based on analysis of the available data, there are two potential transport mechanisms that may lead to channel infilling of the proposed entrance channel, one dealing with fine grain sediment (clay and fine silt) that is transport as suspended load and one involving coarse grain material (sands and coarse silt) that move mostly as bedload or near bottom suspensions. The first mechanism is related to the sediment trap processes that appear to be occurring in the deep pits. Fine-grained sediment travels as suspended load with low settling speeds and is transported by advection and diffusion by the waves and currents. The sediments typically will settle in sheltered and low energy areas, such as the bottom of pits and channels. The deepening and widening of the Norton Basin entrance channel will likely reduce the tidal current speeds in the entrance to Norton Basin, and will also reduce the amount of wave action on the bottom sediments, and consequently, the new channel may act as a trap for accumulating fine-grained sediments. However, estimated peak currents in the channel (see next section) indicate that they will be sufficiently large (> 60 cm/s) to prevent a build-up of fine grained sediment in the channel. One or more sediment cores taken in the existing channel thalweg could confirm this result. The lack of a fine-grain deposit at the surface of those cores would confirm the hypothesis.

The second potential transport mechanism is related to the littoral transport processes typical of narrow, channelized entrances into basins and bays. The development of shoals and bars in the vicinity of the Norton Basin entrance may be evidence of this process. External sources (external to the channel) can be transported to the channel and create deposits. If the transport of sediment to the channel is larger than the transport capacity of the channel, then the channel will begin to fill. Wave-driven, shore-parallel currents transport sediments along the shoreline in shallow water (within the region of wave breaking). Features, such as channels, interrupt the shore-parallel transport, often accumulating sediment at the entrance to the channel. Another potential source of sediment may be from local storm runoff. The rate of shoal development and channel infilling depends on the sediment grain size, hydrodynamic energy and sediment supply to the area. The sediment supply may have changed significantly in the past decades with the completion of the Edgemere Landfill.

In the next section quantitative analysis has been conducted to estimate the hydrodynamic characteristics of the channel, sediment transport rates delivering sediment to the channel and ultimately the potential shoaling rates and stability of the proposed channel.

A quantitative analysis has been developed to estimate the future potential shoaling rates and channel stability of the proposed channel configuration. The analysis is divided into three sections:

(1) assessment of hydrodynamic characteristics

(2) sediment sources and transport rates

(3) channel shoaling and stability

The primary approach for estimating channel infilling due to littoral processes is based on modeling analysis using M2D and STWAVE models via the SMS graphical user interface (GUI). M2D is a coupled time-dependent 2D depth-averaged circulation, sediment transport and morphodynamic model. The model is based on the numerical solution of the depth-averaged mass and momentum equations on a Cartesian grid network and is supported by the USACE. The circulation model component supports wind, tide and wave radiation stress forcing, and includes special features such as flooding and drying, wind-speed dependent (time-varying) wind-drag coefficient, variably-spaced bottom-friction coefficient, time-and space-varying wave-stress forcing, efficient grid storage in memory, and hot-start options. Sediment transport is forced by the circulation model derived currents and coupled wave models (STWAVE and WABED). Various bedload and suspended load models such as Lund-CIRP and Van Rijn formulations are available via user options in the model. The sediment transport model is coupled to a morphodynamic module that calculates time-dependent changes in the bed elevation. The hydrodynamic grid is then updated to reflect the depth changes, which then completes the coupling.

STWAVE (STeady-state spectral WAVE model) (Resio, 1987, 1988a, 1988b; Davis 1992; Smith, Resio, and Zundel 1999) is a phase-averaged spectral energy wave model based on a steady-state finite difference solution to the wave-action balance equation. It simulates depth-induced wave refraction and shoaling, current-induced refraction and shoaling, depth- and steepness-induced wave breaking, diffraction, wind-wave growth, and wave-wave interaction and white-capping, that redistributes and dissipates energy in a growing wave field.

The SMS GUI also provides an automated means of coupling M2D with STWAVE (Smith et al. 1999, Smith et al. 2001) through the Steering Module, which is convenient for projects requiring wave-stress forcing for M2D simulations of wave-induced currents and sediment transport.

4.1 HYDRODYNAMIC CHARACTERISTICS

The first set of model simulations were hydrodynamic only and were made to validate the M2D model tidal flow simulation, and determine the effect of the channel modifications on flow in the entrance channel area.

For the first simulation, a model grid was constructed that covered the entire region of Jamaica Bay with increased resolution in the Norton Basin and Little Bay area. The bathymetry for the model grid was adopted from the digital bathymetric dataset described in Section 3.0. Figure 4-1 shows the model grid and the mapped bathymetry. The minimum grid spacing was 5 m, and a time step of 1.5 seconds was used, which was limited by the shallow wave celerity numerical stability constraints. A two day simulation of tidal flows was made to demonstrate that the model correctly simulated the tides. The simulation period is July 1 and 2 of 1988, so the model output could be compared with the measured tide data from within Jamaica Bay during that time period. The model was forced at Rockaway Point, which is the entrance to Jamaica Bay, with tide data from the NOAA Sandy Hook station. The data analysis in section three indicated that there was no tidal amplitude attenuation and only a small phase lag between tides in Jamaica Bay. Therefore, the application of the Sandy Hook data at the bay entrance is justified. A comparison of the simulated tide and measurements for interior station near Norton Basin is shown in Figure 4-2. The tide elevations are well represented. A plot of simulated velocity magnitudes are shown in Figure 4-3. The values for the observation points in Norton Basin and Little **Bay** are on the order of 10 cm/s and 5 cm/s, consistent with the field measurements of currents in 2000 (Barry A. Vittor and Associates, Inc., 2002).

In the next set of simulations, the model domain was decreased to the region adjacent to and including Norton Basin and Little Bay. This reduction in domain allowed for higher resolution of the Norton Basin entrance area without incurring extremely long computational times. The grid, representing the existing channel geometry is shown in Figure 4-4. The minimum cell size which is centered on the entrance channel is 5 meters. Tidal boundary conditions were applied at the western edge of the grid, where the grid crossed Grassy Hassock Channel.

The bathymetry in and around the entrance channel to Norton Basin was enhanced in the refined grid to best represent its actual shape. Note that little is known about the channel except for the small section covered in the high resolution bathymetry of Norton Basin and Little Bay. Therefore, in order to provide an estimate of transport rates and potential channel infilling, a "best guess" approximation of the channel dimensions was made based on anecdotal information. The channel is assumed to be narrow and shallow (4 feet deep at MLLW) with a sill at the outer end of the channel. For modeling purposes, the channel was set at four feet at its outer end, progressively deepening toward 12 feet at the inside end to remain consistent with survey data. The width was set to approximately 30 feet for most of its length, widening towards the interior of Norton Basin.

The refined domain grid also included finer definition of the shoals and shallow water areas adjacent to the channel. Again, these data are discerned from the NOAA charts and aerial images. The model grid was modified manually, as the digital survey data available did not provide sufficient resolution of these areas.

A simulation of tidal flows was made using this grid, and then, the channel dimensions were increased to represent the proposed channel geometry. Another tidal flow simulation was completed for the proposed channel geometry. These simulations provide estimates of the influence of the channel dimensions on tidal current speeds in the channel. The simulated tidal speeds and stages for both cases are shown in Figures 4-5 and 4-6. For the existing channel configuration (Figure 4-5), the tidal speeds in the channel show a marked asymmetry, due to the presence of the shoals. The transition from ebb to flood tide shows a rapid change in direction with the peak speeds occurring just before and after the transition. During this phase the water surface elevation is below the shoal surface and the water is constricted to flow through the channel. As the water surface elevation rises, the shoal is submerged, increasing the cross-sectional area of the entrance and reducing the flow speed. The peak tidal flow speeds are greatest, ranging from 80 to 100 cm/s, in the Jamaica Bay end and mid-section of the existing channel. Speeds decrease over the shoal and further down the channel due primarily to the smaller cross-sectional area assumed for the outer portion of the channel.

The equivalent tidal flow speeds are shown for the proposed channel cross-section in Figure 4-6. The flow speeds on the shoal and the inner observation point are very similar as those areas are not changed by the proposed channel geometry. As expected, the outer and mid-channel speeds are reduced due to the increased depth and width, which increase the cross-sectional area of the channel. The peak flow speeds are reduced from the 80-100 cm/s range to a 60-80 cm/s range. It is important to note that these results are based on an assumed existing geometry of the Norton Basin Entrance Channel, which is not currently documented.

The tidal amplitude for location inside and outside of Norton Basin is shown in Figure 4-7. The difference between the existing channel configuration and the proposed channel are not significant. In comparison to the Grassy Hassock Channel location, the tides inside the basin for both channel configurations show a slight phase lag and minute amplitude attenuation for the low tide portion of the curves. This is due to the constriction of flow into the channel, after the shoals are exposed by the falling tide.

The peak speeds obtained in the model simulations of 60 to 80 cm/s are sufficient to transport non-cohesive sediments in the sand-size range.

4.2 SEDIMENT TRANSPORT

A review of the potential sediment sources has identified two sources for the proposed entrance channel:

Runoff from the Edgemere Landfill estimated to average 1128 cubic yards per year

Littoral transport along the shoreline outside and adjacent to the entrance channel

The load from the Edgemere Landfill is likely to be less than 1128 cubic yards due to the capping, but we have retained this value as a conservative estimate.

In order to estimate the littoral transport the STWAVE and M2D models were employed. The STWAVE model was used to estimate wave conditions as they impinged on the shoreline and entrance channel area. The STWAVE results were then used in an M2D simulation to determine the littoral currents and associated transport. An STWAVE grid was developed form the M2D grid and is shown in Figure 4-8. In order to estimate the higher range of potential littoral transport, the larger waves arriving from the North were used in the initial simulation. They were applied at the northern edge of the STWAVE grid and their propagation across the basin towards the Norton Basin entrance channel was simulated. The wave height and direction resulting from the simulation are shown in Figure 4-9. The waves progate across the deep basin (Grassy Hassock Channel) with little attenuation, refract as they approach the shallower shoals long the shoreline and then eventually break and dissipate. These wave conditions were used in an M2D simulation (without tides) to discern the role of littoral induced currents in the transport. The resulting wave-induced current field for steady wave conditions is shown in Figure 4-10. The current speeds peak at about 20 cm/s and are generally along the shoreline directed from the northeast. The current bends into the entrance channel and crosses the tip of the shoal. On the southeastern edge of the channel, a clockwise eddy is formed with pathlines that circulate from the channel entrance along the shoal and back into the channel further into entrance.

In the next model simulation the tidal forcing and the wind-generated waves (STWAVE outputs) were included in the M2D simulation with the sediment transport module invoked. The results of the simulation indicated that there was no littorally induced transport in the vicinity of the entrance channel (or anywhere else). The sediments were assumed to be coarse silt (a limitation of the M2D sediment transport algorithm) and the wave conditions (0.88 m) were the largest that were estimated to occur based on the wind-wave transformations (Section 3.7). Note that the refraction and wave breaking conditions can be dependent on the local bathymetry in the vicinity of the entrance to the channel, for which it has been noted that there is a lack of data. Therefore, in order to confirm these results, the littoral transport was estimated using wave energy dissipation methods that are described in the USACE Shore Protection Manual (USACE, 1984). These methods are less dependent on local bathymetric conditions and use wave dissipation theory combined with transport rate formulas to estimate littoral sediment transport rates along open coastlines. In order to apply this method, the wave height period and direction data developed in Section 3.7 was used. Focusing on the direction bins that could lead to littoral transport towards the channel entrance, the associated transport rates were calculated. The results for transport due to waves from the north and from the west are shown in Tables 4-1 and 4-2.

When the annual frequency of occurrence for each wave height and direction class are considered, the transport rates of sediment towards the entrance channel for waves from the North is 60.40 cy/yr and for waves originating from the west, it is 19.76 cy/yr. The total transport rate to the channel entrance is on the order of 80 cy/yr. For comparison, in the Gulf Coast of the U.S., typical rates may vary from 10's to 100's of thousands of cy/yr. Thus the estimated rates in the Norton Basin channel are very small.

4.3 ANALYSIS OF CHANNEL SHOALING AND STABILITY

The hydrodynamic and sediment source analysis provided in the previous two sections can be integrated to estimate the potential future shoaling rates and general stability characteristics of the proposed channel. The purpose of this analysis is to determine the potential for channel shoaling (infilling) that would require future maintenance dredging work. Two approaches have been employed to estimate potential shoaling rates. The first is based on additional M2D model simulations invoking sediment transport calculations. The second approach is based on a method developed by Kraus (1998).

The M2D high-resolution model grid, configured for the proposed entrance channel with the same tidal forcing as that used in the hydrodynamic model simulations, was used for the sediment transport analysis. The Lund-Cirp transport formulation was used with a grain size of 0.06 mm (fine sand). The results of the simulation indicate that minimal transport is occurring in and around the channel, except during low tide conditions when the flow into and out of Norton Basin is confined to the channel. Figure 4-11a and 4-11b show the magnitude of the simulated transport during the rising and falling tides (corresponding to hours 17 and 26 in figure 4-7). The transport is confined to the channel bottom with peak values in the bend of the proposed channel. Peak transport rates are on the order of 0.001 m^3/m-s and a spatially averaged rate is on the order of 0.0002 m^3/m-s. In order to express this rate on an annual basis, we can assume that the rate occurs about 12% of the tidal cycle (24% for both flood and ebb tides). This assumption yields an annual average transport rate of 11,500 m^3/yr. This rate is large relative to the estimated sediment delivery to the channel of 1000 m^3/yr, and therefore, it is expected that the tidally-induced channel flows can remove the external sediment load. In fact, the model simulations indicate that the channel may deepen and widen until the average velocity is reduced, and consequently, the sediment transport rate is reduced.

It is interesting that the current channel configuration appears to be unaltered by the model-estimated high flow velocities. The predicted flow velocities are sufficient to scour typical non-cohesive sediments, but there is no evidence that the channel cross-sectional area is widening or deepening. There are a number of possible reasons for this result, including the possibility that the sediments may be well packed or exhibiting cohesive behavior. Either of these conditions could increase the critical stress for erosion and limit the sediment transport of existing bed sediments. Additionally, the channel geometry in the narrow sections is based on anecdotal information and therefore the model may not be representing the true geometry at the channel entrance area. Possibly the current channel geometry may have reached some atypical equilibrium shape due to the high sediment load during the build-out of the Edgemere Landfill.

Another analysis was employed to calculate the equilibrium channel cross-section area based on a method developed by Kraus (1998). This method is derived by balancing sediment delivery to the channel and sediment transport capacity in the channel. The equilibrium cross-sectional area is related to physical parameters according to:

$$A_E = C_p P^{0.9}$$

where A_E is the equilibrium channel cross-sectional area, P is the tidal prism, and C_p is defined as

$$C_p = \left(\frac{a p^3 C_k m^2 W_E^{1.33}}{Q_g T^3} \right)^{0.3},$$

where a and C_k are empirical coefficients, m is manning's n, W_E is the equilibrium cross-sectional area, Q_g is the sediment delivery to the channel (via littoral transport or other means) and T is the tidal period. The values used in the calculation are shown in Table 4-3. The values for a and C_k are adopted from suggested values in the referenced article. Use of these values yields an estimate of the equilibrium cross-sectional area of 89 m^2. The proposed channel cross-sectional area is 84 m^2.

This analysis indicates that the proposed channel is near an equilibrium cross-sectional area, and should therefore remain stable with little need for maintenance. The underlying implication in the analysis is that the transport capacity of the tidal flows in the channel is sufficient to remove the sediment that is transported to the channel via littoral or other processes. In this analysis, it was assumed to be approximately 1000 m^3/yr.

Table 4-1

Estimated Littoral Transport Rates for Waves Originating from the North

	Bin Direction (deg)	Wind Speed (m/s)	Wave Height (m)	Angle (deg)	Percent Occurence	Transport Rate (m^3/yr)	Weighted Transport Rate (m3/yr)
SOUTH DIRECTED TRANSPORT	337.5	0-2	0	17.5	0.13	0	0
	337.5	2-4	0	17.5	1.49	0	0
	337.5	4-6	0.23	17.5	2.62	83.62	2.19
	337.5	6-8	0.30	17.5	1.77	315.70	5.58
	337.5	8-10	0.40	17.5	0.73	1330.38	9.76
	337.5	10-12	0.46	17.5	0.19	2675.86	5.06
	337.5	12-14	0.55	17.5	0.03	6538.64	2.11
	337.5	14-16	0.65	17.5	0.01	15074.43	0.90
	337.5	16-18	0.54	17.5	0.00	5965.45	0
	337.5	18-20	0.78	17.5	0.00	37510.01	0
	337.5	20-22	0.88	17.5	0.00	68562.63	0
	0	0-2	0	40	0.21	0	0
	0	2-4	0	40	2.00	0	0
	0	4-6	0.23	40	2.30	115.32	2.66
	0	6-8	0.30	40	1.26	435.39	5.48
	0	8-10	0.40	40	0.42	1834.72	7.70
	0	10-12	0.46	40	0.12	3690.27	4.41
	0	12-14	0.55	40	0.03	9017.43	2.57
	0	14-16	0.65	40	0.01	20789.11	1.10
	0	16-18	0.54	40	0.00	8226.93	0
	0	18-20	0.78	40	0.00	51729.96	0.00
	0	20-22	0.88	40	0.00	94554.57	1
	22.5	0-2	0	62.5	0.25	0	0
	22.5	2-4	0	62.5	2.19	0	0
	22.5	4-6	0.23	62.5	2.17	57.82	1.26
	22.5	6-8	0.30	62.5	0.97	218.29	2.13
	22.5	8-10	0.40	62.5	0.34	919.89	3.13
	22.5	10-12	0.46	62.5	0.10	1850.22	1.78
	22.5	12-14	0.55	62.5	0.03	4521.15	1.22
	22.5	14-16	0.65	62.5	0.00	10423.22	0.40
	22.5	16-18	0.54	62.5	0.00	4124.81	0.03
	22.5	18-20	0.78	62.5	0.00	25936.30	0
	22.5	20-22	0.88	62.5	0.00	47407.65	0

Table 4-2

Estimated Littoral Transport Rates for Waves Originating from the West

	Bin Direction (deg)	Wind Speed (m/s)	Wave Height (m)	Angle (deg)	Percent Occurence	Transport Rate (m^3/yr)	Weighted Transport Rate (m3/yr)
NORTHEAST DIRECTED TRANSPORT	247.5	0-2	0	72.5	0.17	0	0
	247.5	2-4	0	72.5	2.72	0	0
	247.5	4-6	0.22	72.5	3.02	21.11	0.64
	247.5	6-8	0.25	72.5	1.21	40.00	0.48
	247.5	8-10	0.30	72.5	0.40	99.54	0.40
	247.5	10-12	0.40	72.5	0.14	419.47	0.59
	247.5	12-14	0.46	72.5	0.04	843.70	0.30
	247.5	14-16	0.55	72.5	0.02	2061.64	0.34
	247.5	16-18	0.62	72.5	0.01	3752.82	0
	247.5	18-20	0.70	72.5	0.00	6884.77	0
	247.5	20-22	0.74	72.5	0.00	9089.88	0
	270	0-2	0	50	0.11	0	0
	270	2-4	0	50	1.46	0	0
	270	4-6	0.22	50	2.04	77.48	1.58
	270	6-8	0.25	50	1.54	146.82	2.26
	270	8-10	0.30	50	0.75	365.33	2.75
	270	10-12	0.40	50	0.30	1539.51	4.57
	270	12-14	0.46	50	0.07	3096.51	2.11
	270	14-16	0.55	50	0.02	7566.53	1.36
	270	16-18	0.62	50	0.01	13773.41	0.94
	270	18-20	0.70	50	0.00	25268.14	0.96
	270	20-22	0.74	50	0.00	33361.20	0

Table 4-3

Parameter Values for the EquilibriumCross-sectional Area Formulation

Parameter	Value
a	1
p	3.14159
C_k	1
m	0.025
W_E	22.9 m
Q_g	1000 m^3/yr
T	12.4 hrs
P	1,000,000 m^3

An investigation of the future shoaling rate of the proposed entrance channel to Norton Basin has been completed. The analysis indicates that the proposed channel cross-section is close to an estimated equilibrium cross-sectional area, and therefore, the shoaling rates are expected to be small. The entrance area to Norton Basin is dominated by tidal currents. The tidally-induced current speeds in the channel, based on depth-averaged hydrodynamic modeling of the channel, indicate sufficient speeds, on the order of 60 to 80 cm/s, to maintain self-scouring conditions in the channel. Based on these findings, it is estimated that the shoaling rates in the proposed channel are expected to be very low, and the channel should be able to maintain a self-scouring condition for the anticipated annual sediment loads of 1000 cy/yr.

Aside from the large tidal currents, the area surrounding Norton Basin is relatively sheltered and wind-generated wave energy is relatively low. The sediment delivery via littoral transport has been estimated to be low. The only other documented source of sediment available to the area is dependent on stormwater runoff from the Edgemere landfill. The annual load is on the order of 1000 cy/yr. Should the entire load arrive at the channel, the predicted channel hydrodynamic characteristics should be capable of removing the full sediment load.

Despite these favorable findings, the analysis is based on a number of crucial assumptions. Some evidence exists that might conflict with these findings. The assumptions and potential impacts are listed below. Note that most of these are born of a lack of field data that are typically available for transport studies.

(1) A number of assumptions as to the local geometry were necessary to complete the analysis. The assumptions as to the existing bathymetry were necessary to validate the hydrodynamic model. For both the existing and proposed channel bathymetry, the assumption of the shoal extent and elevation and exposed "island" can have significant effect on the current speeds in the channel and consequently the conclusion of the shoaling analysis.

(2) The grain size data collected at the site focused on deep pits. There was no data characterizing the sediments on the shoals and in the existing channel near the entrance. The presence of cohesive effects, if found to exist, could alter the conclusions of the analysis.

(3) The wind-wave transformations in the area have not been validated with site-specific measurements and do not include effects such as reflection and diffraction. However, these effects are considered to be small for the Norton Basin entrance area. If larger waves than those estimated were actually to occur, then a larger sediment load may be transported to the entrance of the channel

(4) One of the critical assumptions in the analysis is that the historic shoaling that has filled the outer end of the entrance channel was due to relatively large, historic sediment loads. These loads are attributed to sediment available during the build-out of the Edgemere Landfill, which is no longer occurring. If the shoaling at the entrance to the historic channel has continued after the completion of the build-out, then there are other processes contributing to the sediment load in the channel. If this load continues to be available at a higher rate than the 1000 m^3/yr that has been assumed in the analysis, then the proposed channel may shoal at a faster rate.

(5) The estimated speeds in the existing channel are quite large (~ 1 m/s), suggesting that the channel should be scouring. The current belief is that the existing channel geometry has not changed significantly since 1996, and therefore, the modeling results are inconsistent with the observations. These observations, indicating that no change or very slow change is occurring at the site, are anecdotal and may also be incorrect. Additionally, the geometry of the existing channel and shoals is based on assumptions and it is unclear whether cohesive processes are affecting sediments in the channel bottom, thereby limiting their mobility.

It should be pointed out that most channel designs and dredging estimates rely on site-specific historic records to validate and constrain the analysis. Typically, modern channel projects involve the deepening and widening of existing, previously-maintained navigation channels to accommodate larger vessels characteristics of modern commerce. In this particular case, however, an existing channel is being resurrected with only anecdotal historic information about the historic evolution of the channel. Therefore, the usual practice of constraining the analysis with historic data are not viable. Any interpretation of the analysis results and conclusions need to incorporate these limitations.

Given the limitation of historic data, there are a number of assumptions in the analysis that can be eliminated with additional data collection. These include the following:

1) Bathymetry in the shallow areas in and around the entrance to Norton Basin
2) Grain size sampling and analysis of samples collected in the shallow areas around the entrance to Norton Basin.
3) Current measurements in the entrance channel to Norton Basin and the adjacent shoals.

Finally, the analysis indicates that the highest transport rates occur in the sharpest bend in the channel configuration. The channel alignment should therefore follow the general contours of the present alignment while maintaining the most minimal and constant curvature possible. This will help eliminate the possibility of channel migration or at least minimize the potential rate of channel migration.

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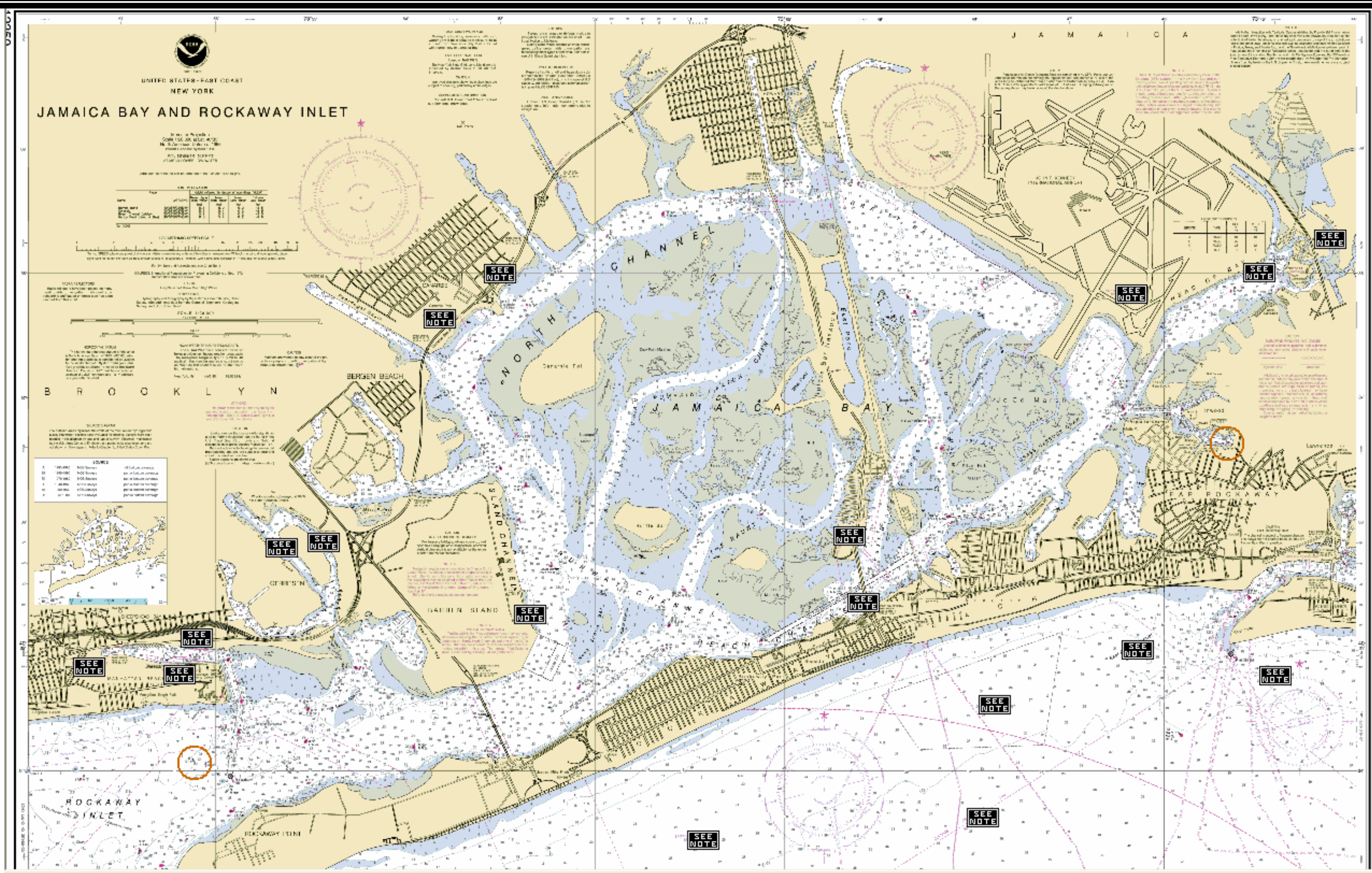
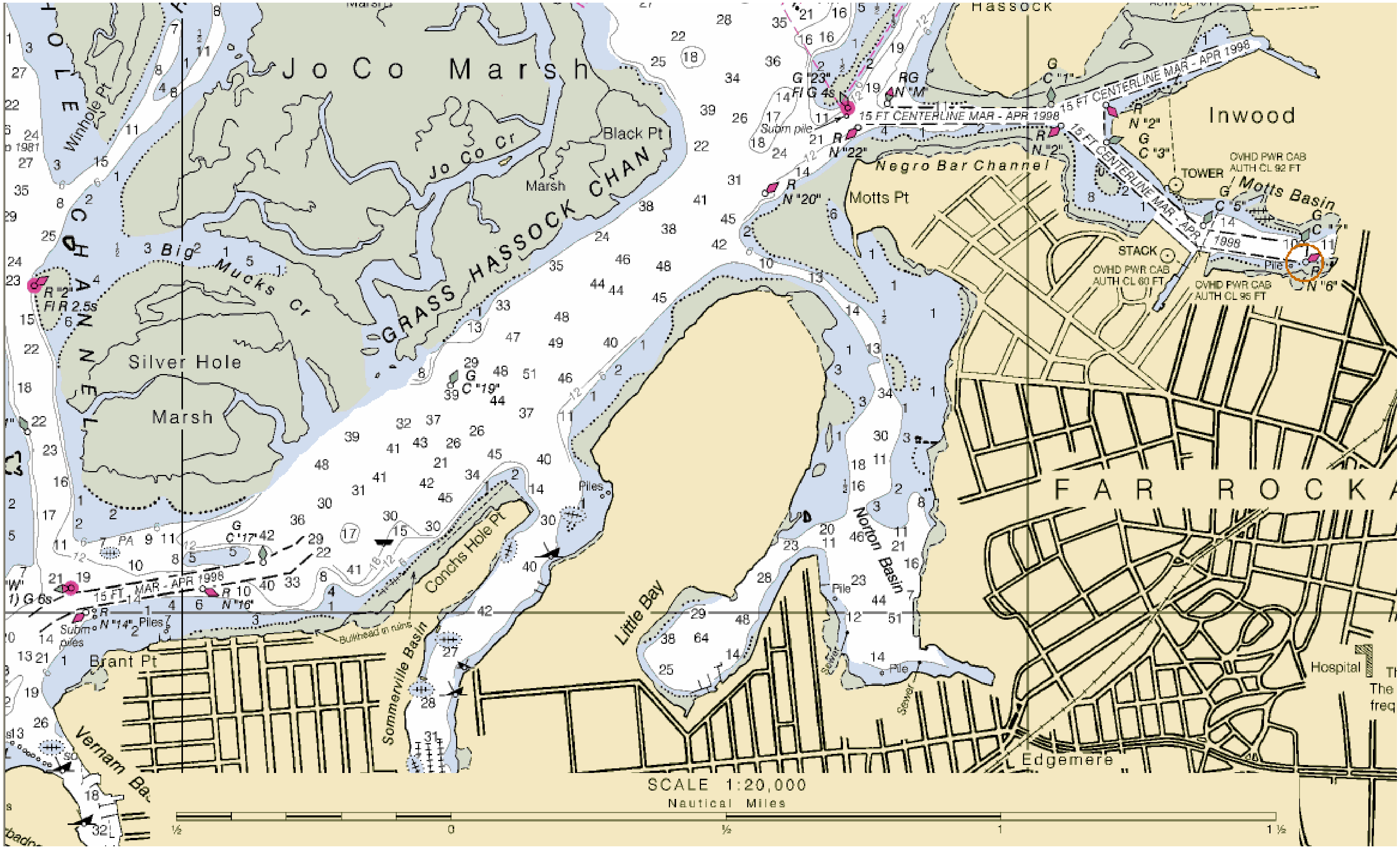


URS

NOAA Navigational Chart For Jamaica Bay

Figure 2-1



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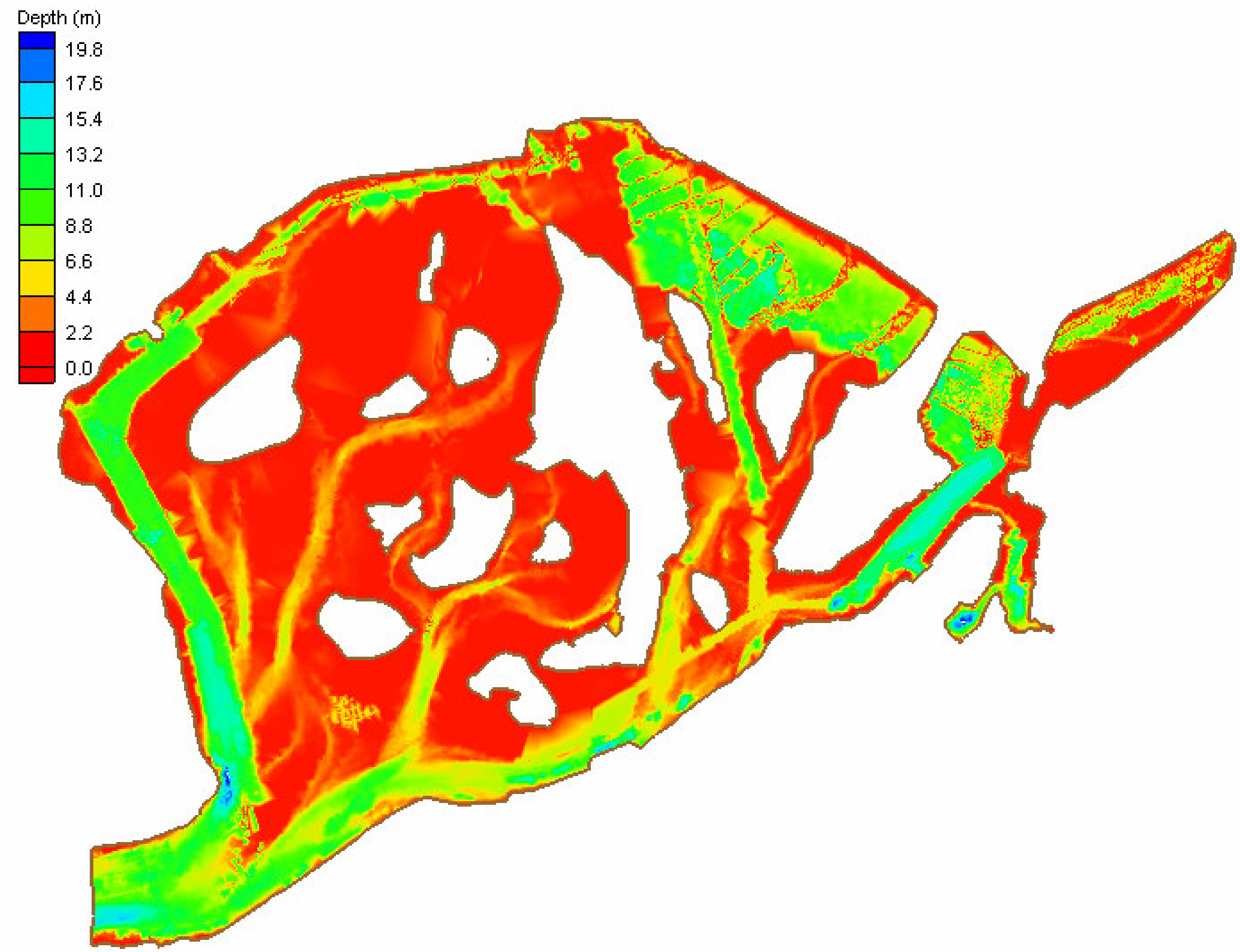
NOAA Navigational Chart For Jamaica Bay-
Norton Basin, Little Bay, and Grassy Hassock Channel

Figure
2-2



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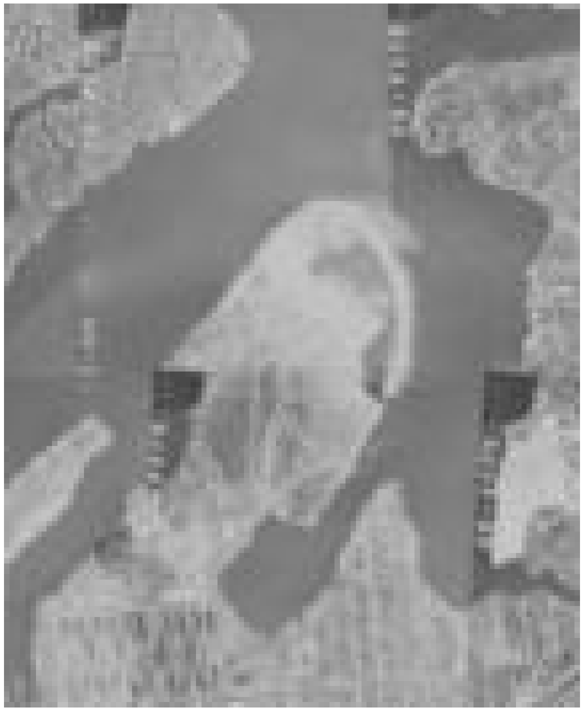
Bathymetric Soundings of Jamaica Bay
Based on Digital Databases

Figure
3-1

1954



1966

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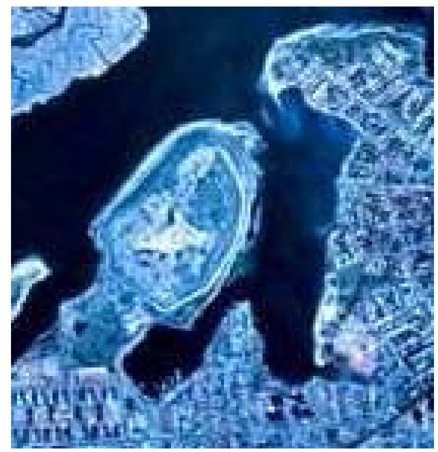
Aerial photographs of Norton Basin and Little Bay
showing construction of Edgemere Landfill,
with completion prior to 1966

Figure
3-2

1966

1974

1985

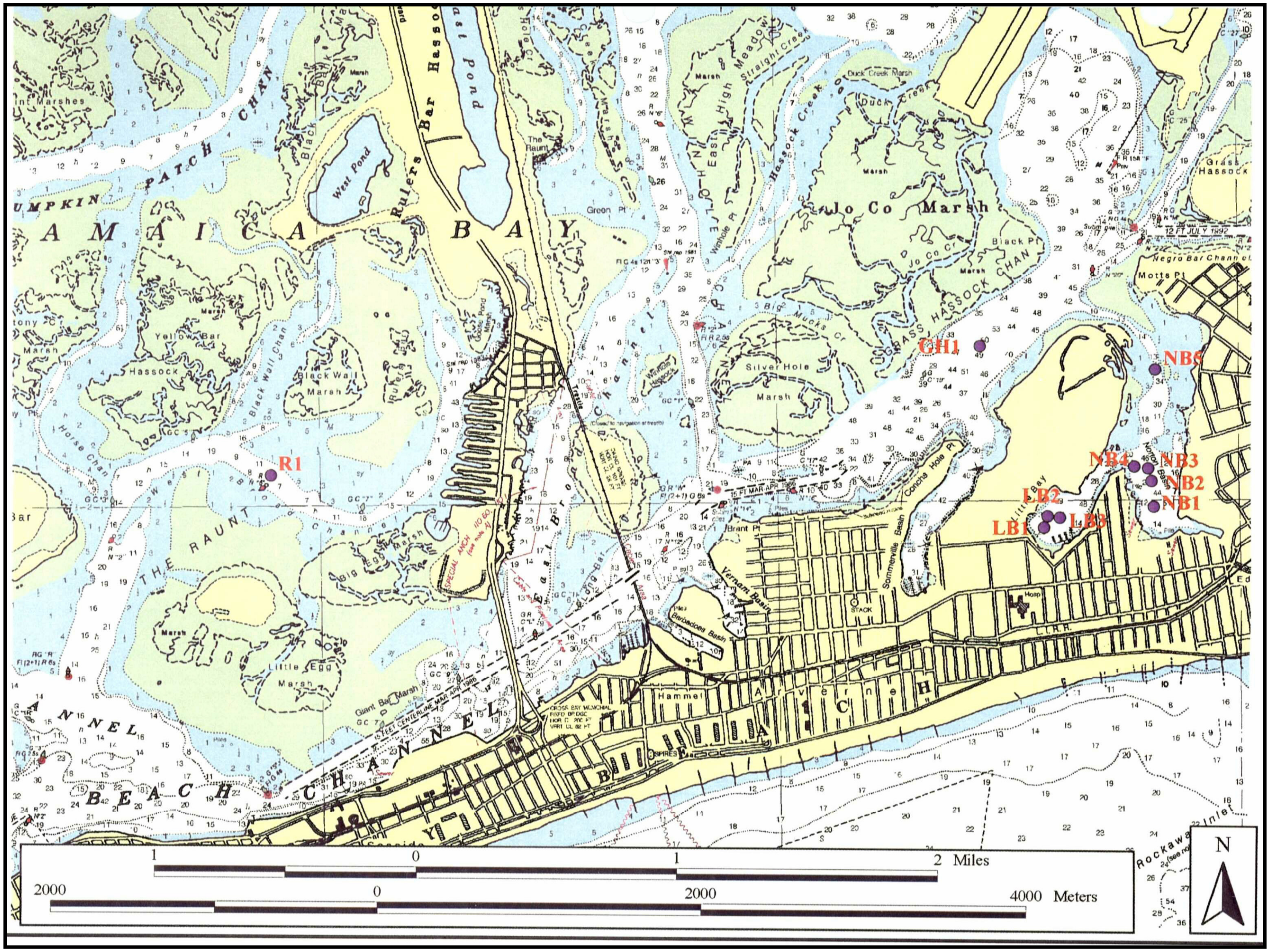


1994

URS

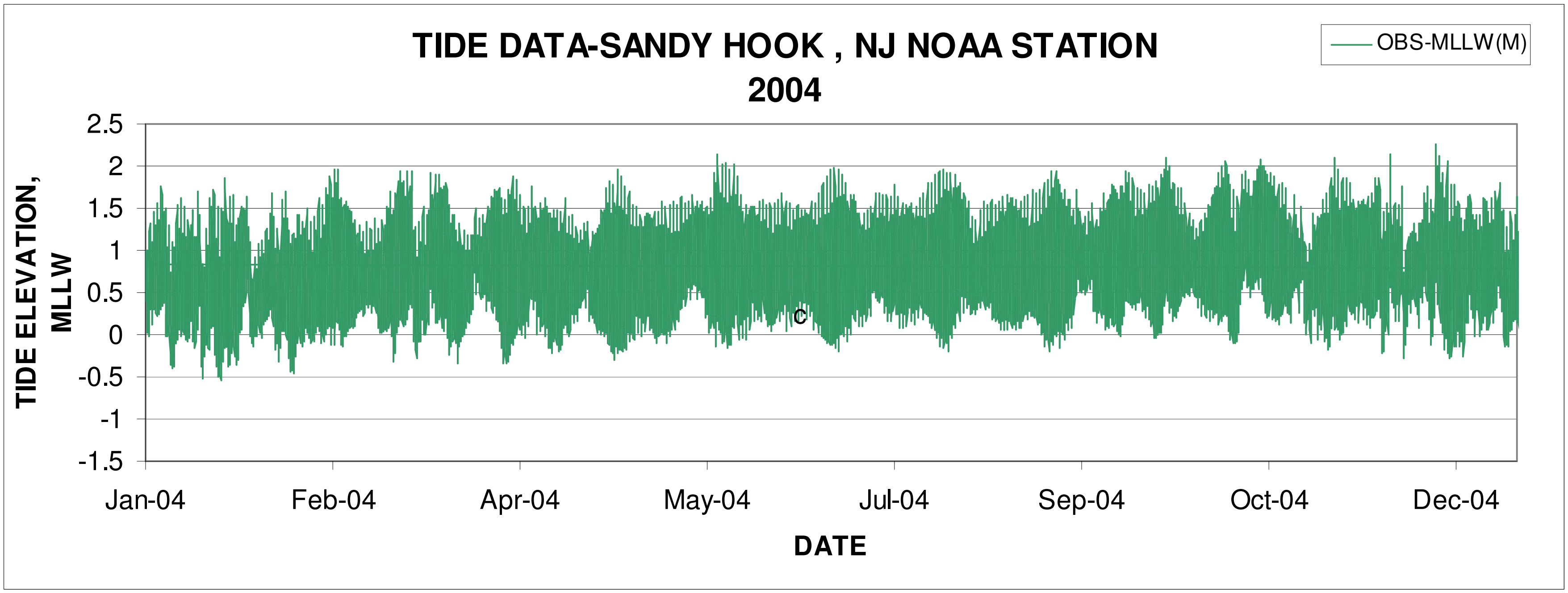
Aerial photographs of Norton Basin and Little Bay
Showing entrance channel and shoal development

Figure
3-3



Sediment Sample locations collected by
Barry A Vittor, and Assoc., 2002
(Reproduced from Vittor, 2002)

Figure
3-4



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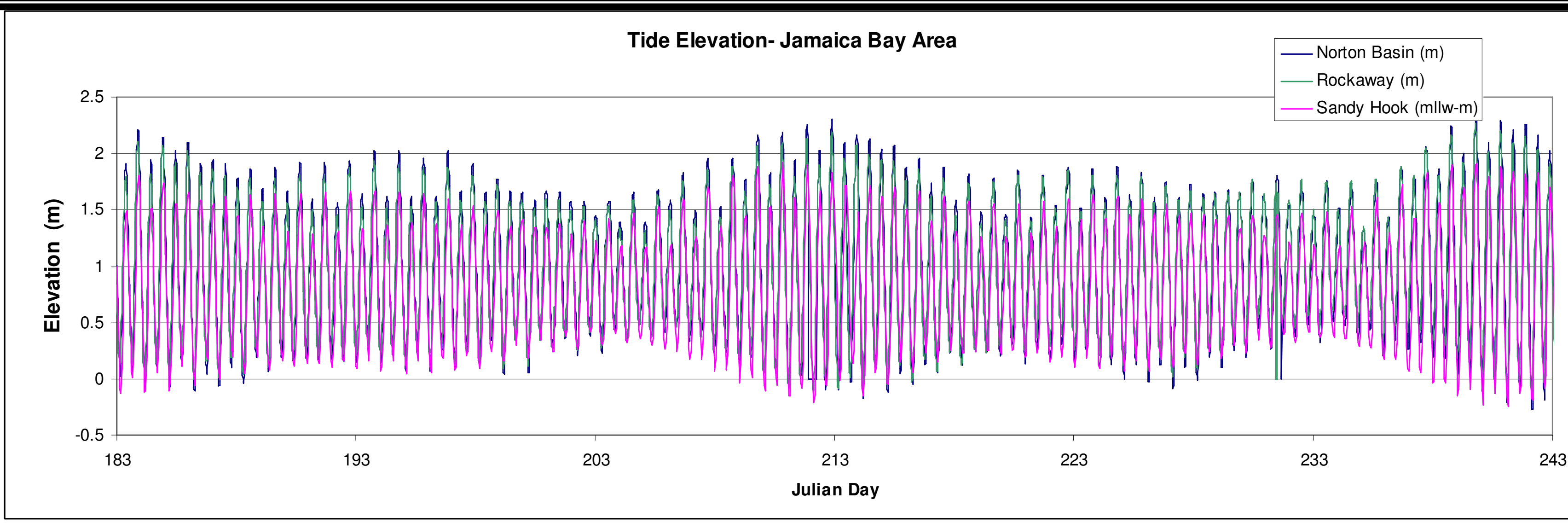
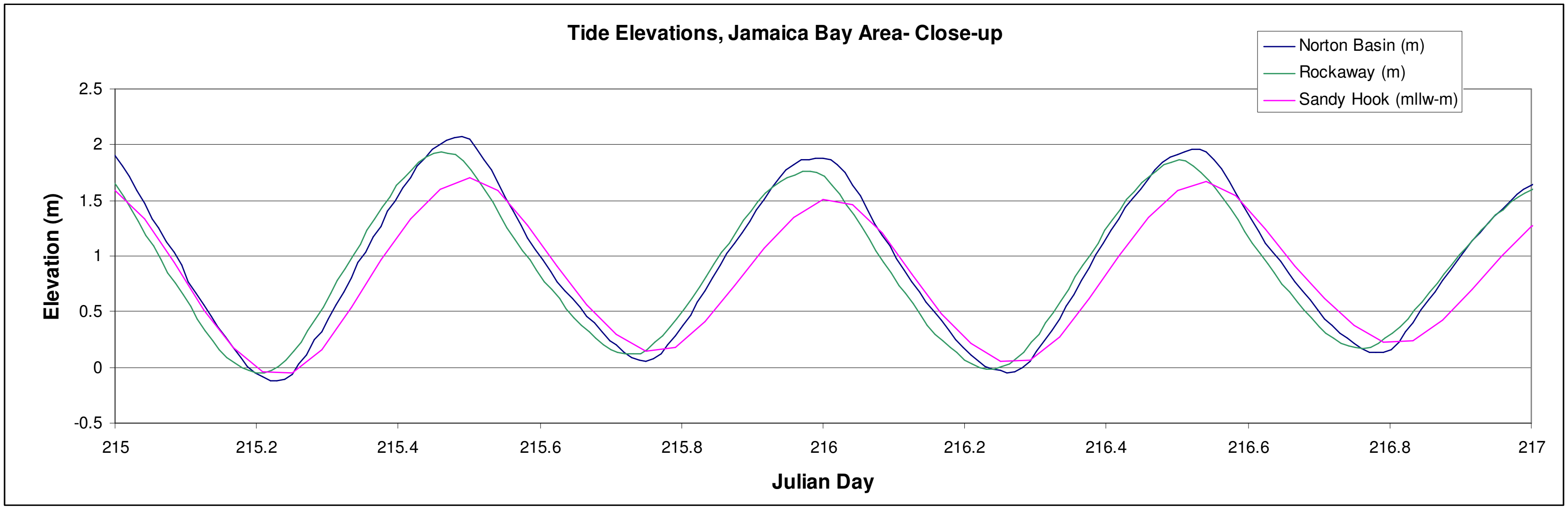
Representative sample of tide data for
Sandy Hook, NJ Tide Station
(January through December, 2004)

Figure

3-5

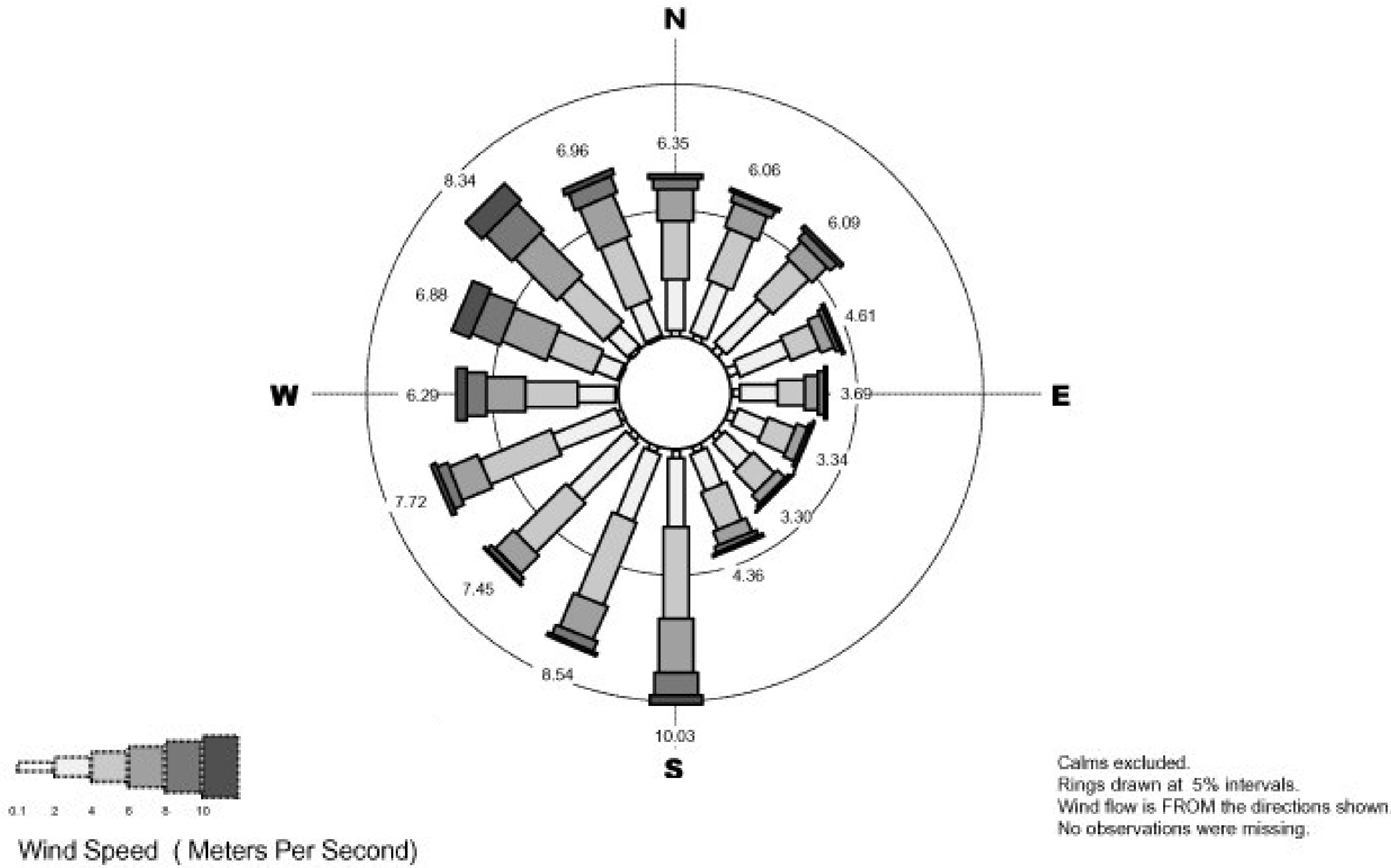




URS

Local Tide Data for Norton Basin Inlet and Rockaway Inlet
During July and August, 1988
Compared to Sandy Hook, NJ Tide Station Data

Figure 3-6



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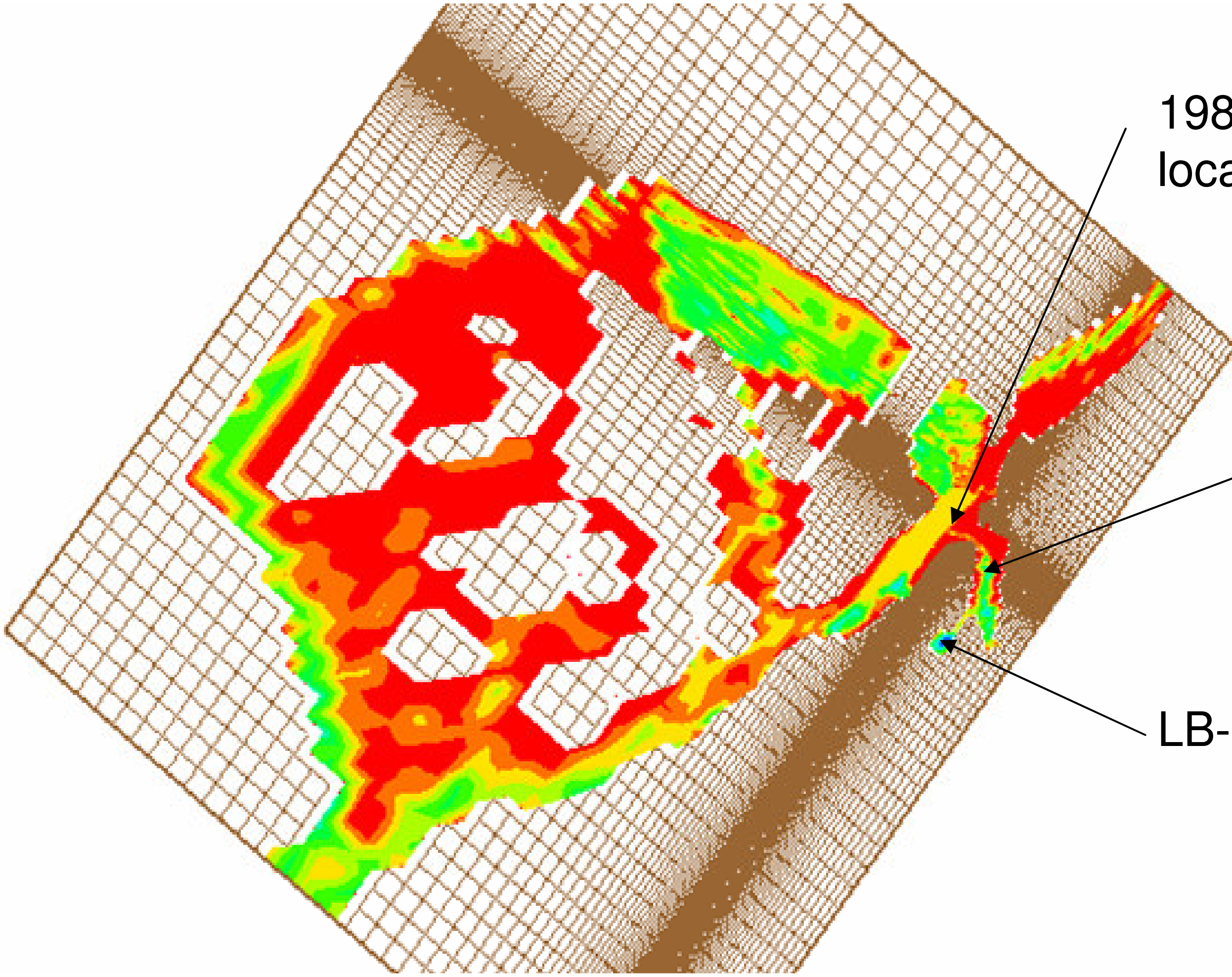
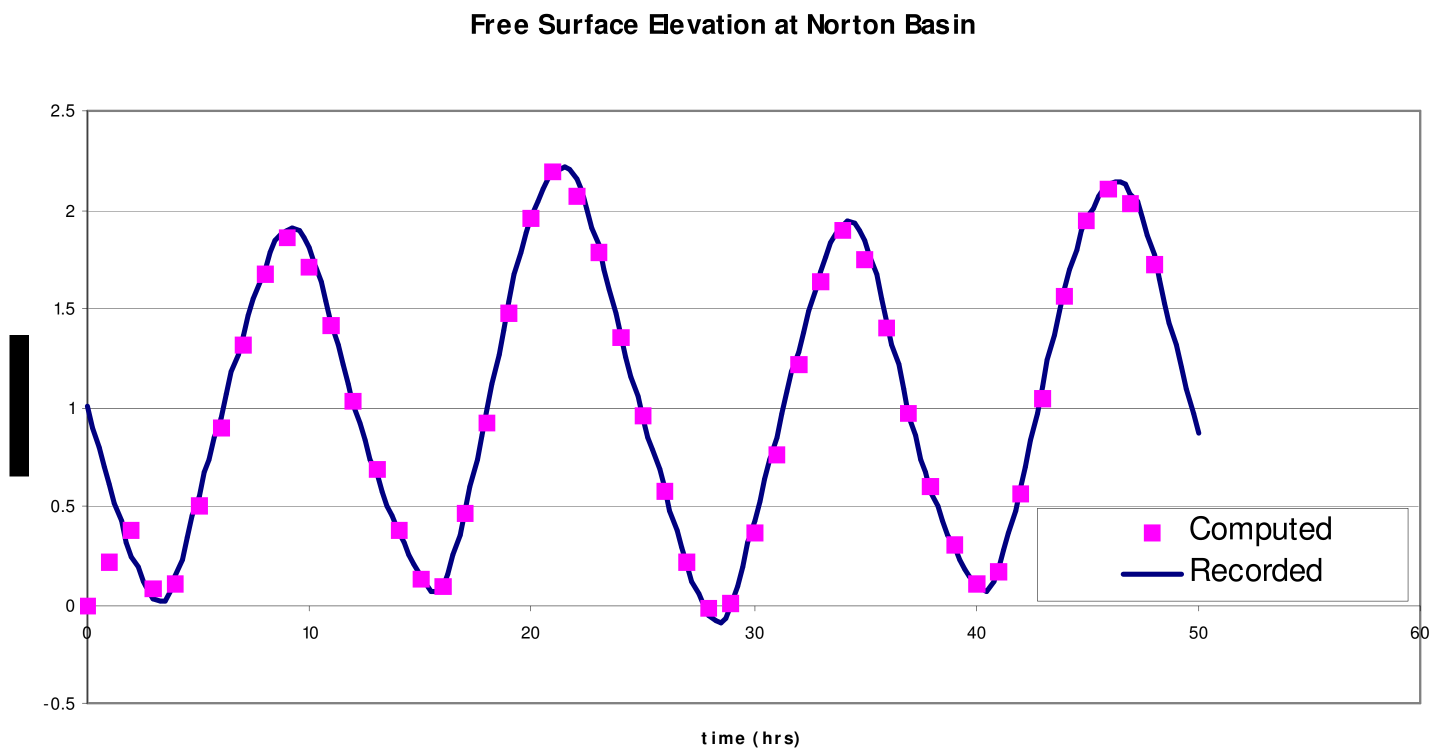
Joint Frequency Distribution Wind Rose Diagram
JFK International Airport Wind Station (#74486)
January, 1990 through December, 2004

Figure
3-7



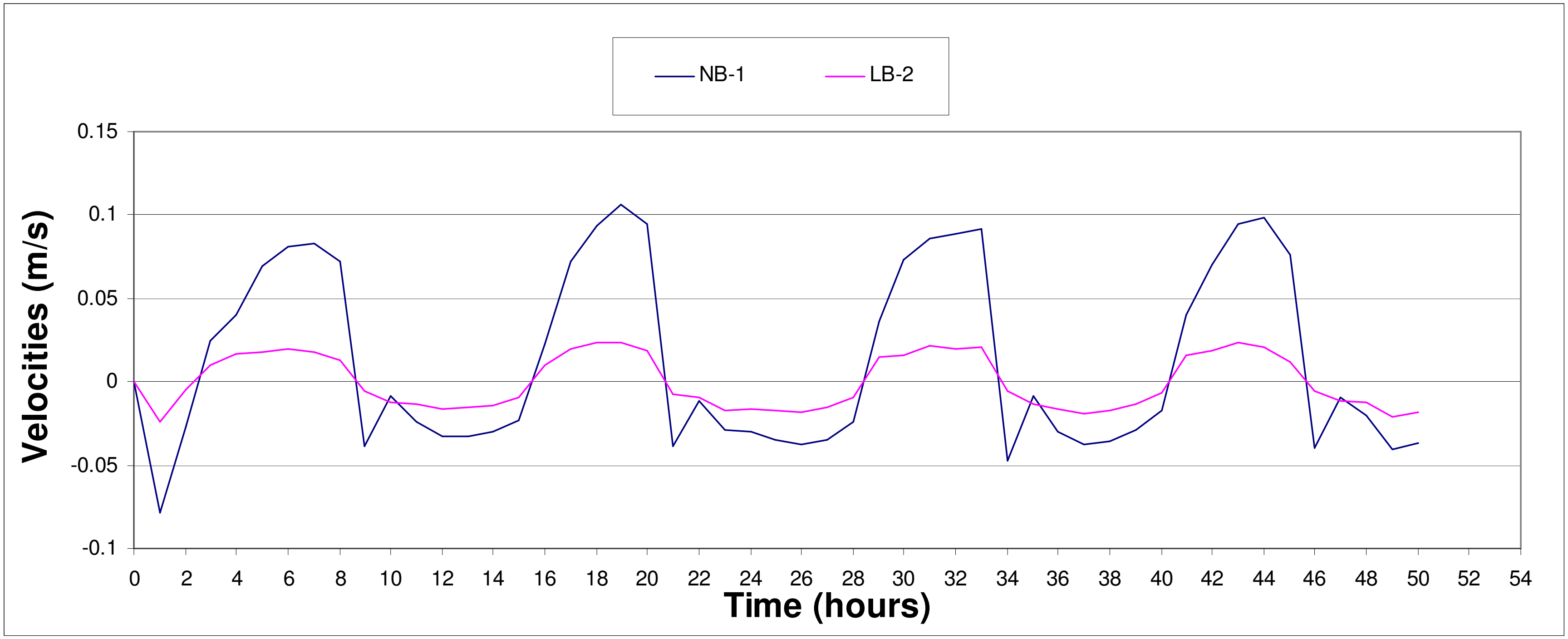
Bathymetric Soundings of Norton Basin and Little Bay

Figure 4-1



Comparison of measured and simulated water surface elevations at the entrance to Norton Basin

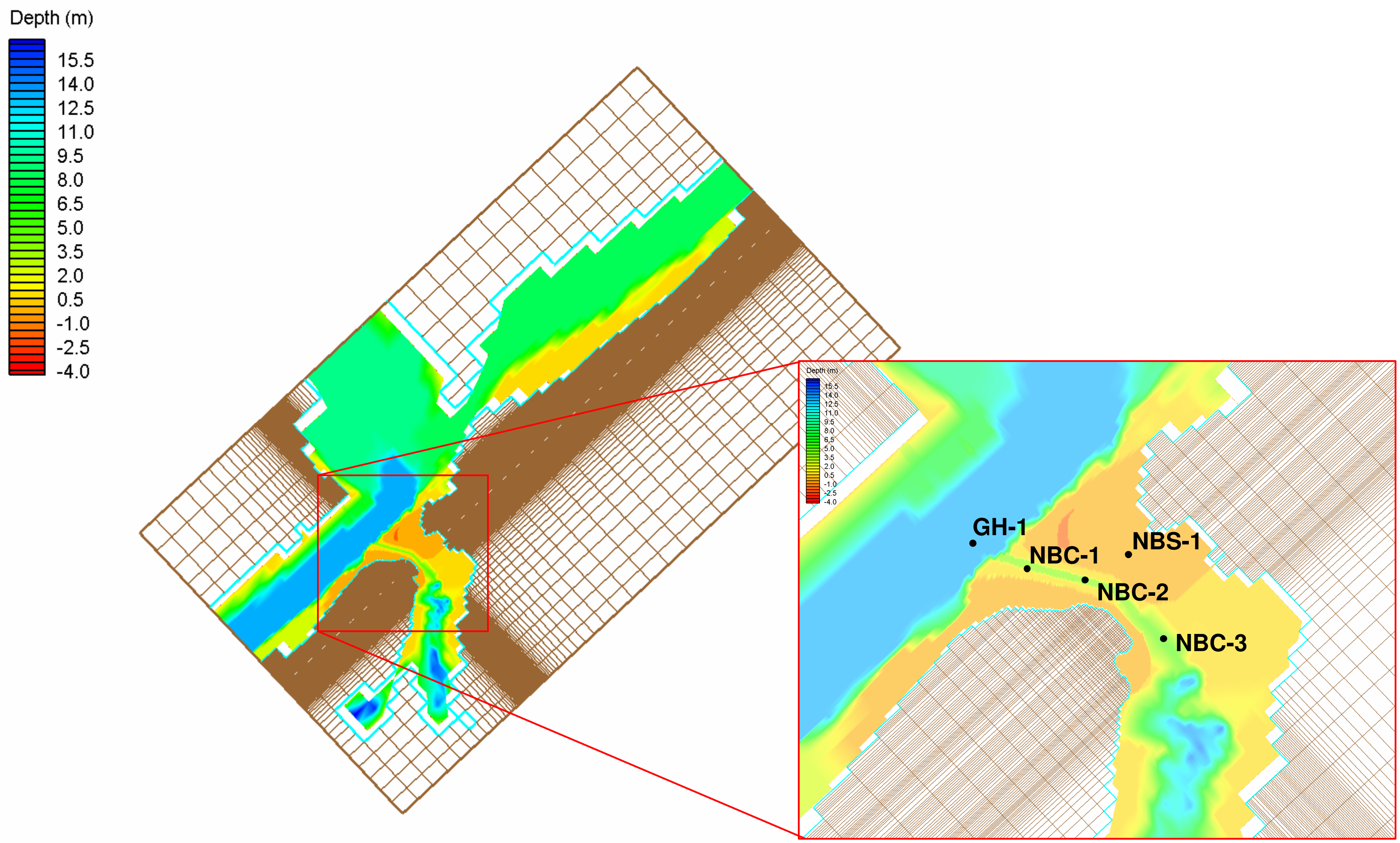
Figure 4-2



URS

Simulated tidal velocities in Norton Basin and Little Bay (see Figure 4-1 for observation point locations)

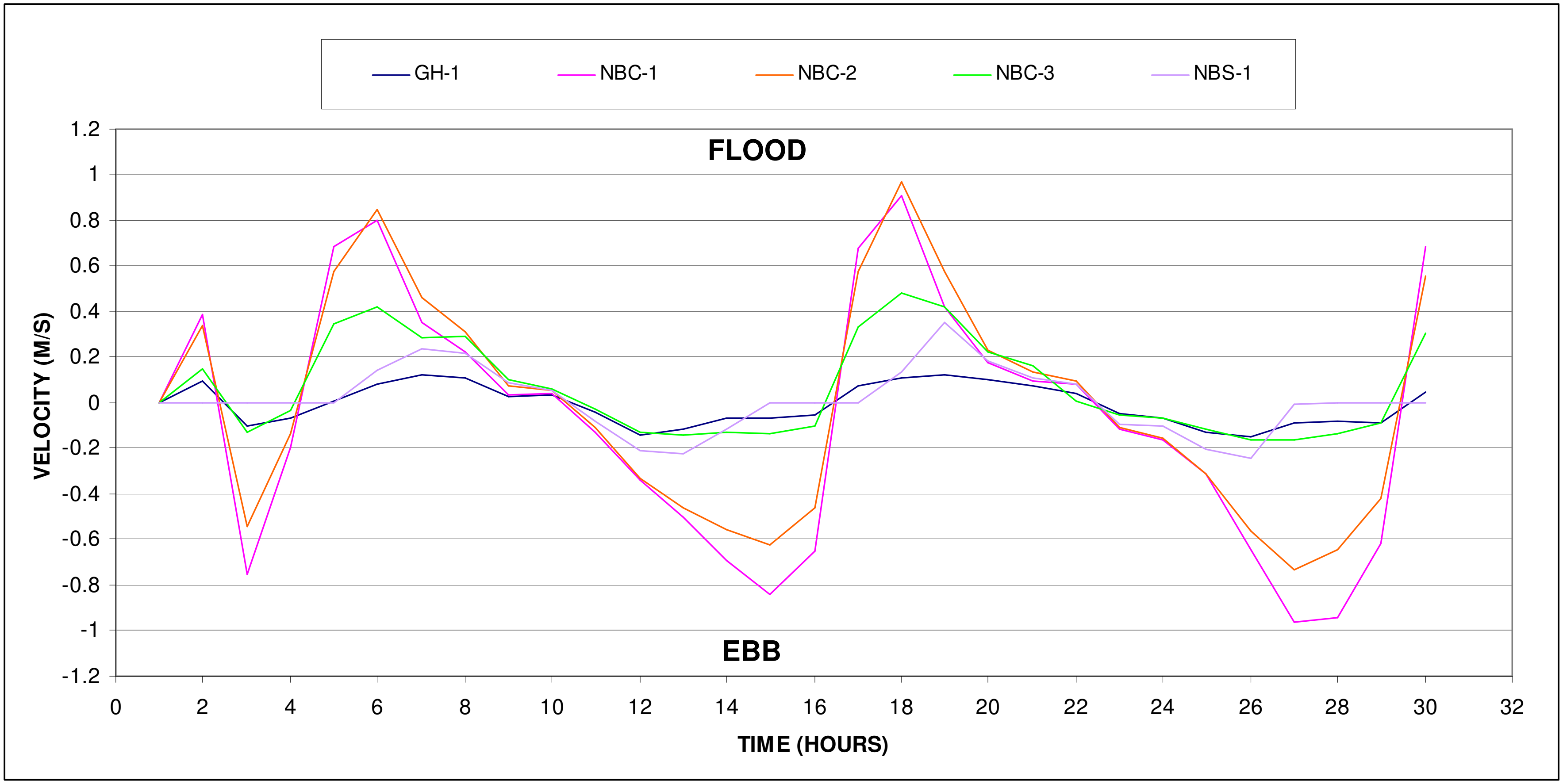
Figure 4-3



URS

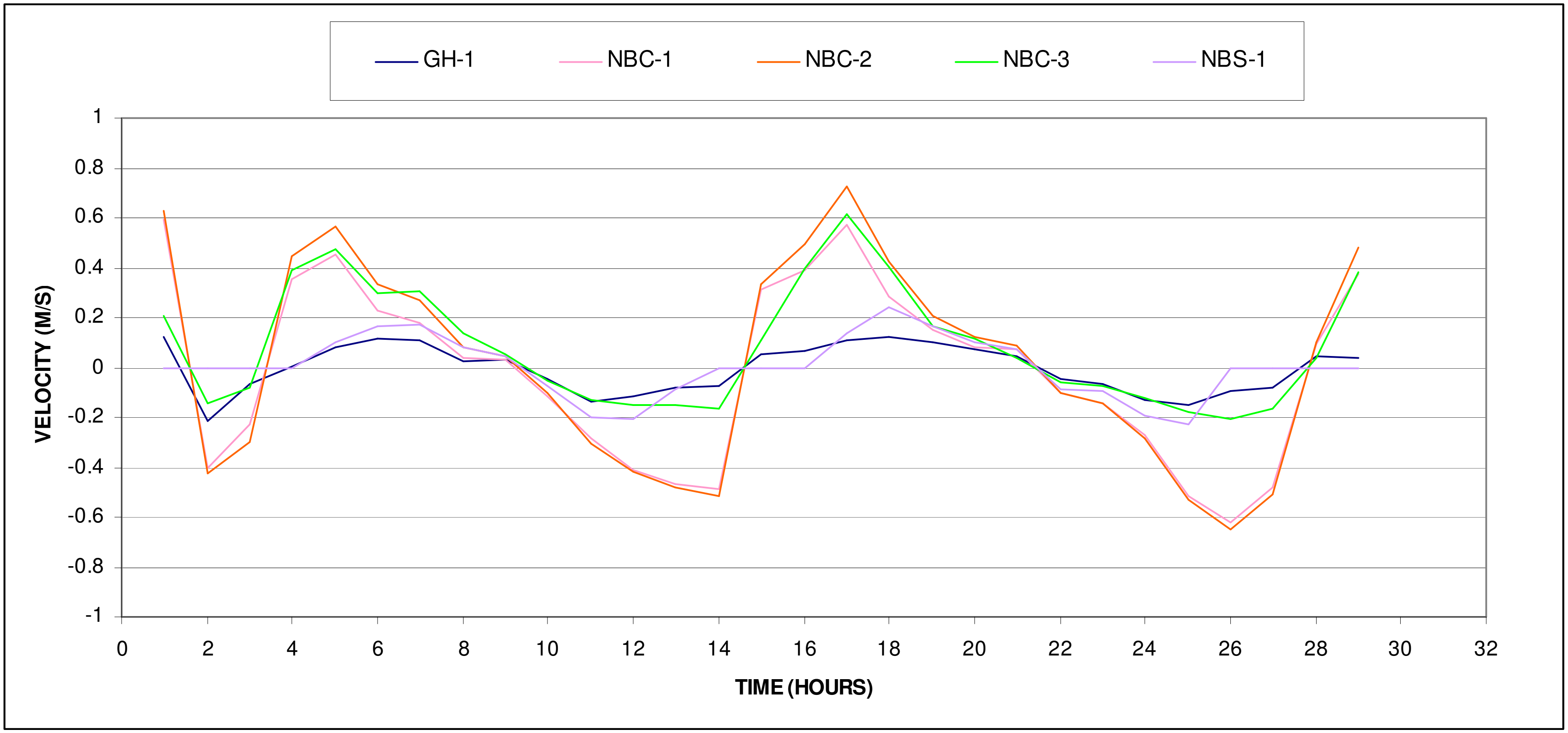
Refined M2D Grid and Observation Point Locations in Norton Basin Entrance Channel and Shoal

Figure 4-4



Simulated Tidal Flow Speeds in the Vicinity of the Existing Norton Basin Entrance Channel

Figure 4-5



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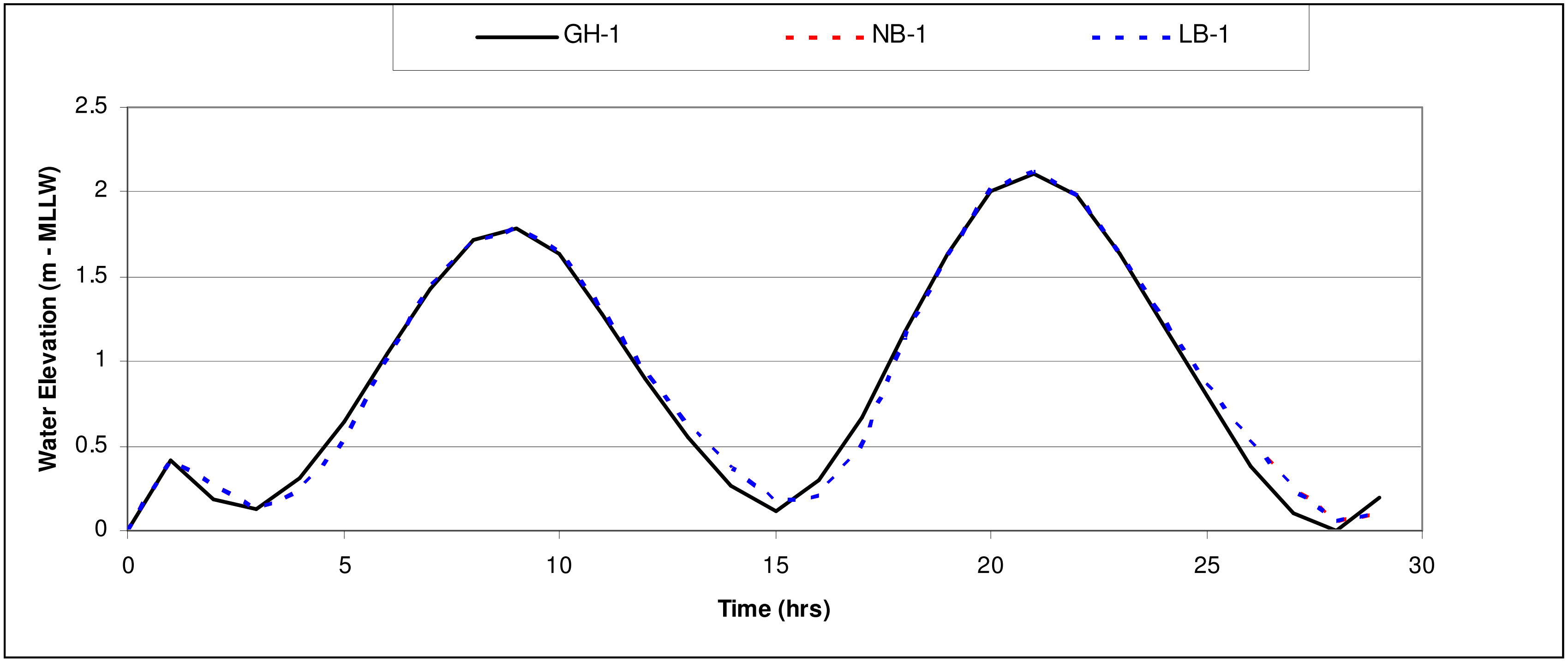
Simulated Tidal Flow Speeds in the Vicinity of the Proposed Norton Basin Entrance Channel

Figure 4-6



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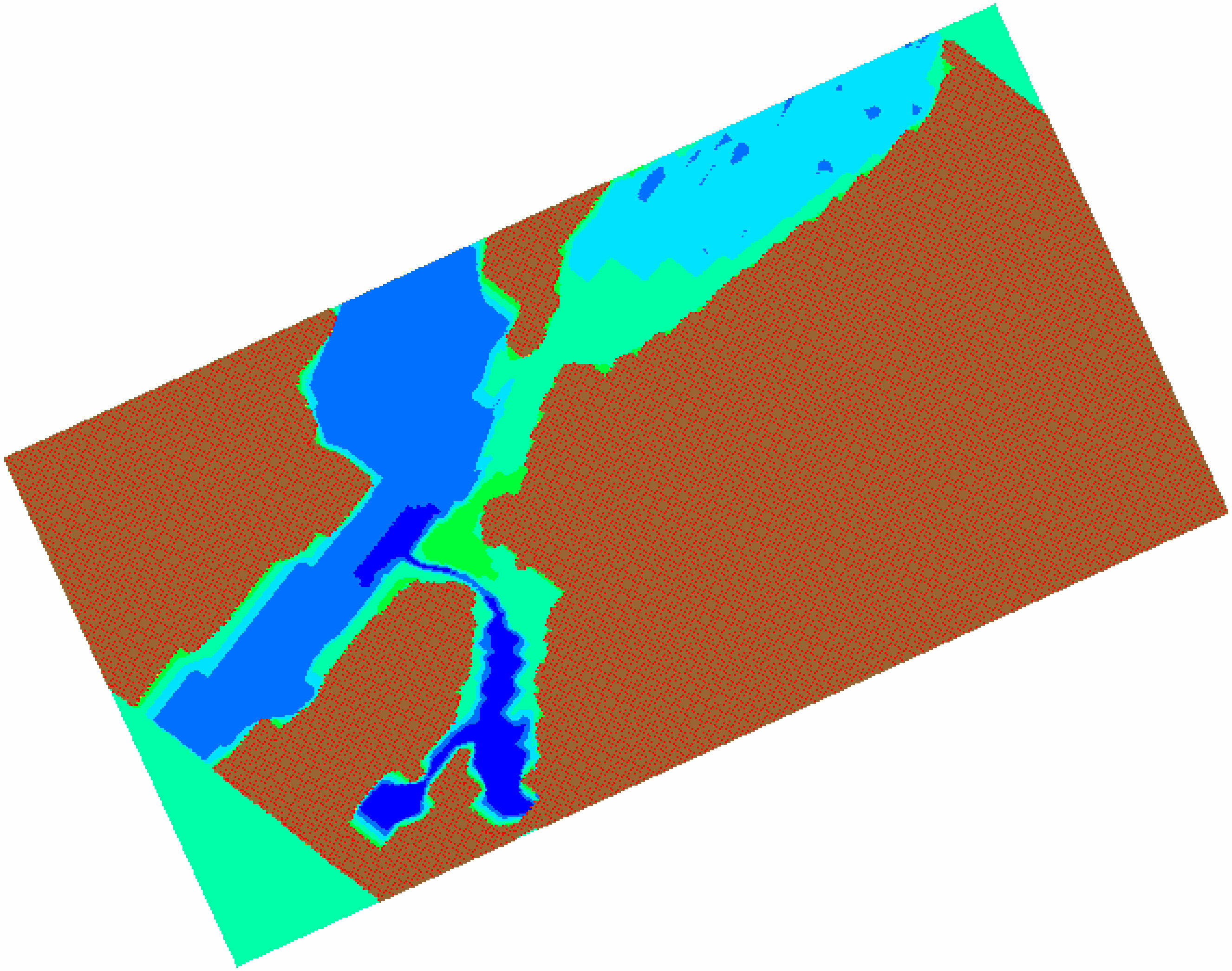
Simulated Tidal Amplitude in Norton Basin

Figure 4-7



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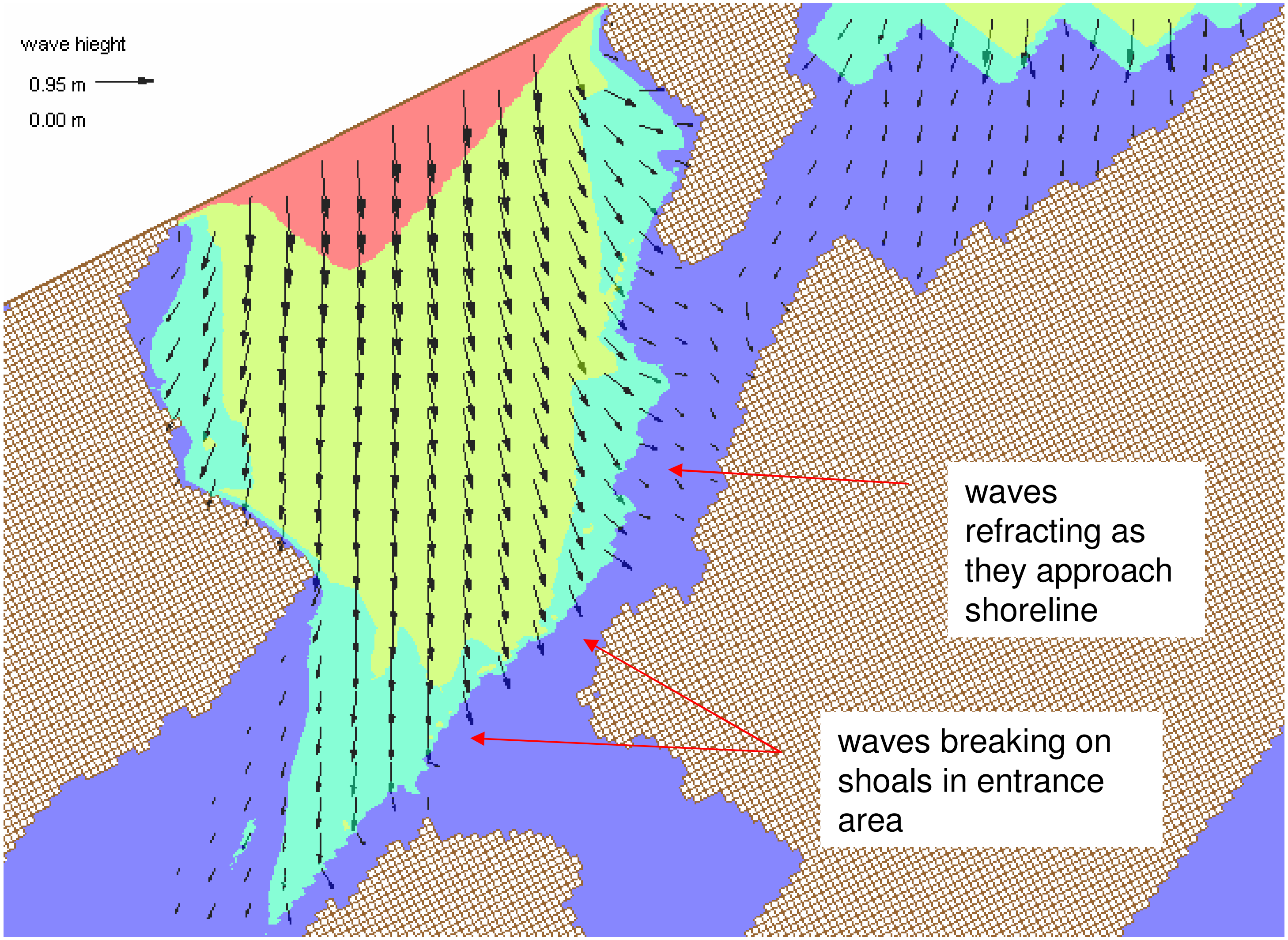
Model Grid for Wave Simulations

Figure 4-8



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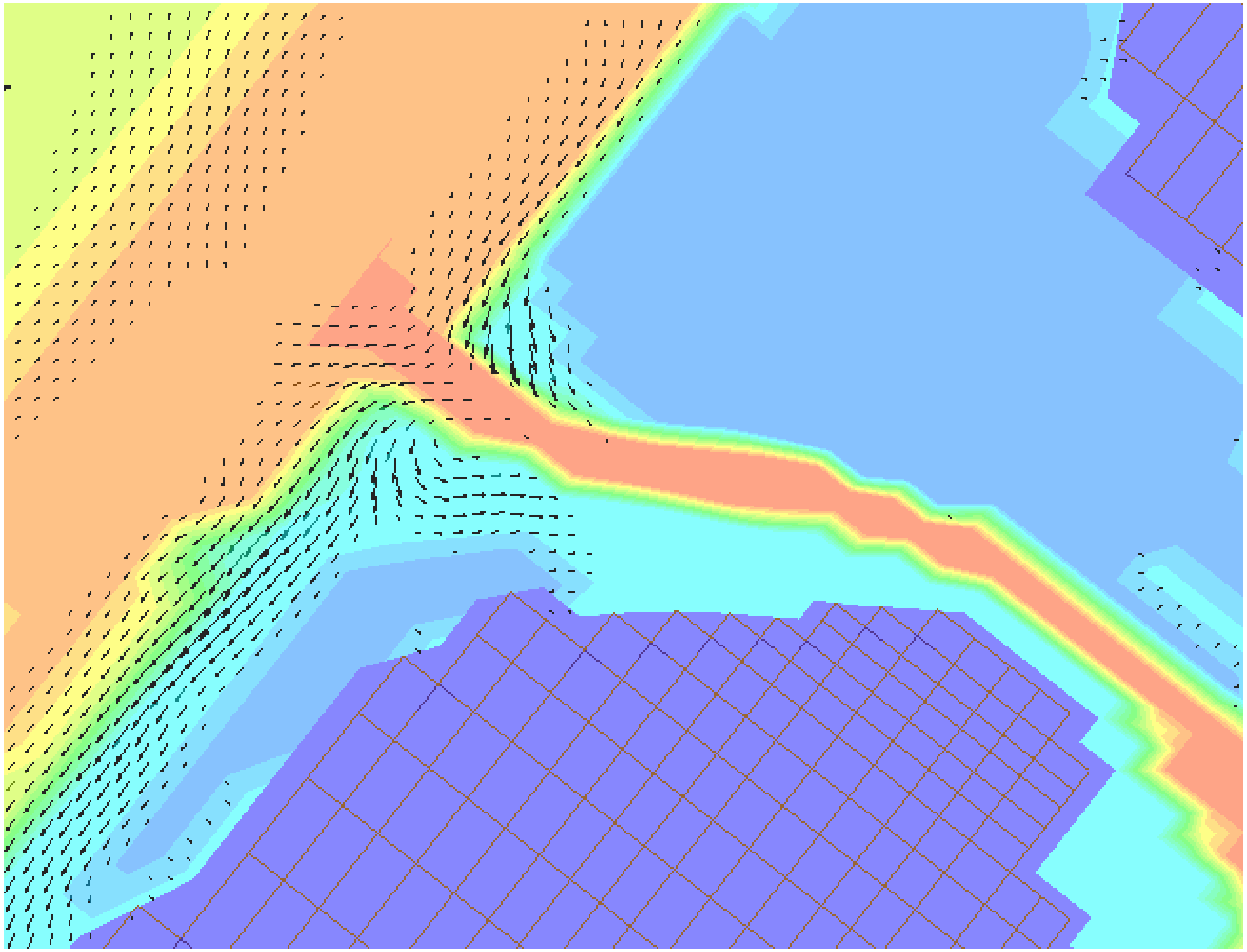
Simulated Wave Field: Wind Generated 0.8 m Waves Propagating Towards Norton Basin Entrance

Figure 4-9



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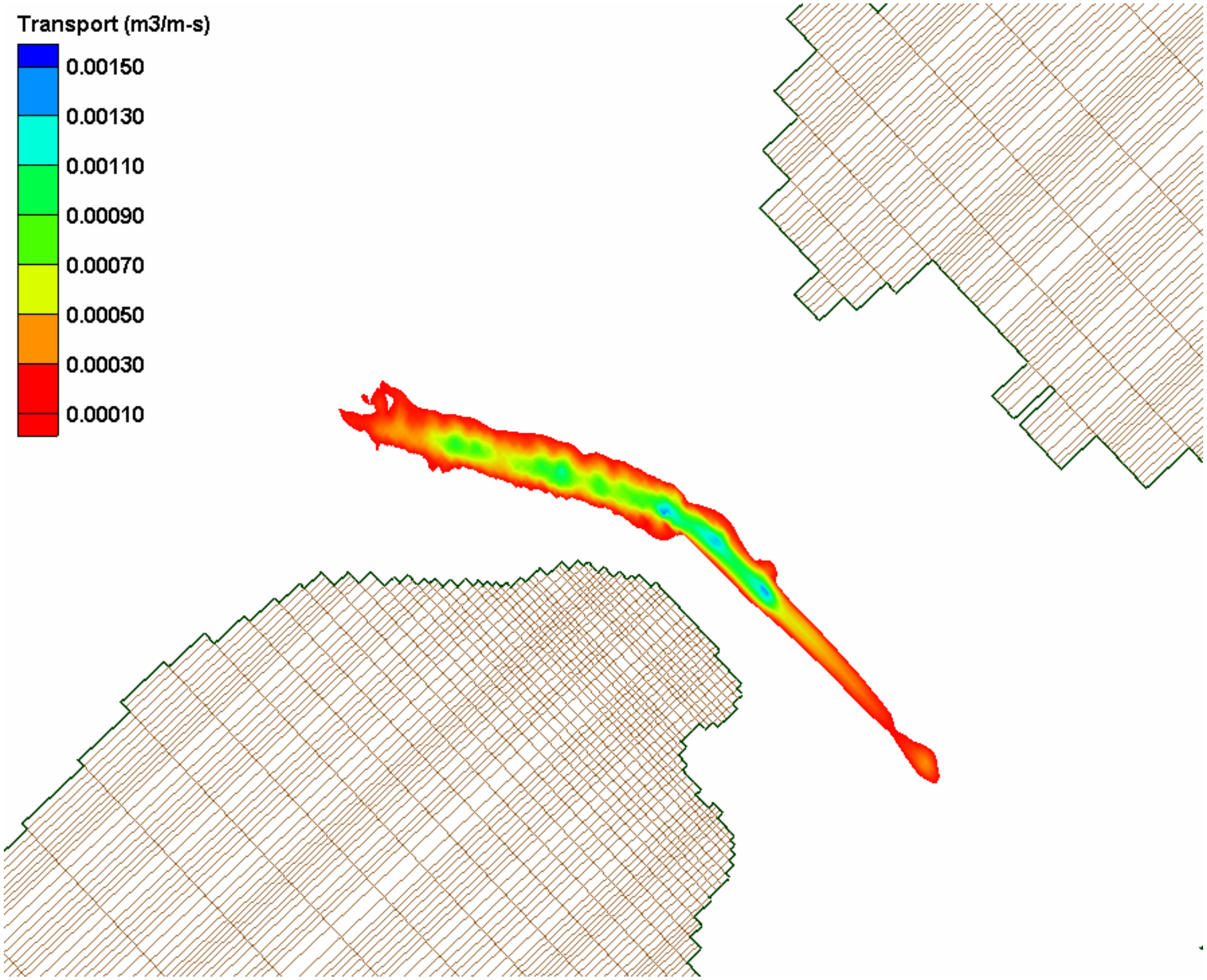
Simulated Current Pattern Induced by Wave
Radiation Stress Gradients

Figure
4-10



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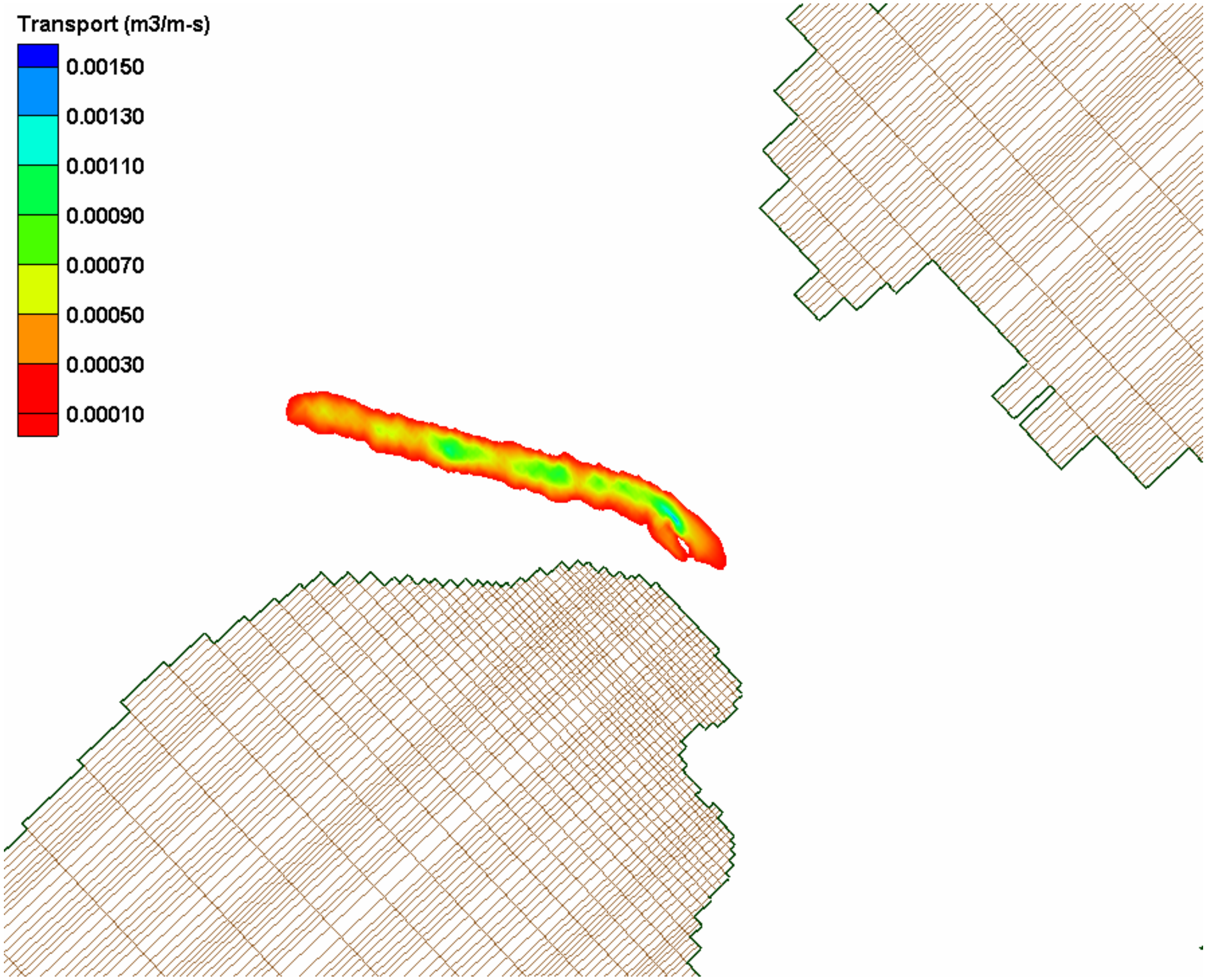
Simulated transport during rising tide for the proposed channel configuration

Figure 4-11a



URS

Simulated transport during falling tide for the proposed channel configuration

Figure 4-11b